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ORIGINAL ARTICLES

STUDIES IN INDIAN PULSES

THE INHERITANCE OF MORPHOLOGICAL CHARACTERS AND OF WILT-RESISTANCE IN *RAHAR* (*CAJANUS INDICUS* SPRENG.)

BY

F. J. F. SHAW, D.Sc. (Lond.), A.R.C.S., F.L.S., I.A.S.,

Director and Imperial Economic Botanist, Imperial Institute of Agricultural Research

(Received for publication on 21st December 1935)

(With Plates XXIII—XXVI)

Introduction

The property of disease resistance is generally a physiological quality which cannot be visibly identified by an observer in the same way as a morphological character. It may happen that a resistant type owes its resistant quality to some definite visible morphological character or that certain morphological characters, not in themselves directly concerned in the quality of resistance, are invariably present in a resistant type. Where this is the case the recognition of resistant individuals is easy.

In the case of the wilt disease of *rahar*, *Cajanus indicus* Spreng. (pigeon-pea), the existence of resistance in certain pure lines has been already demonstrated. It has been shown that a high degree of resistance is present in the Pusa Type 80 and that resistance is also possessed by Types 16, 41, 50, 51 and 82 [McRae and Shaw, 1933].

For the study of the inheritance of wilt-resistance it was necessary to select two types of *rahar* one of which possessed a high degree of resistance and another which was characterised by a marked susceptibility to the disease. Fortunately the Pusa Type 5 was all that could be desired in this latter respect, this type giving about 100 per cent deaths due to wilt in an artificially infected field. By growing the F_1 and F_2 generations of a cross between Type 5 and the resistant Type 80 in artificially infected fields the percentage loss due to wilt in these generations was determined.

The cross was grown in F_1, F_2 and F_3 generations both in fields which had been artificially infected and in fields which were not artificially infected. In this way by comparing the phenotypic frequencies in the surviving plants of the F_2 in the infected area with those in the F_2 grown under normal conditions it was possible to determine whether the quality of resistance was restricted to, or increased in, any particular phenotypes. The F_3 and subsequent generations grown under infected conditions as well as under normal conditions served to elucidate the inheritance of wilt resistance.

Part I

THE INHERITANCE OF MORPHOLOGICAL CHARACTERS—CHARACTERS OF PARENTS AND F_1

The characters of the parents have already been described and are shown with those of the F_1 in the following table :—

TABLE I

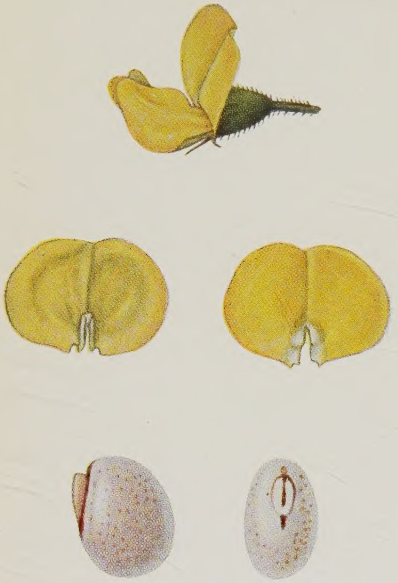
Characters of parents and of F_1

Type	Habit	Inflo-rescence	Flower	Pod	Seed
Type 80 .	Spreading and tall.	Open .	Yellow with diffused red colour on dorsal side of standard	Green with black streaks	Light fawn with brown markings (patches)
Type 5 .	Erect and short	Crowded	Yellow . .	Green with black streaks.	Silver-white with faint grey dots.
F_1—Type 80 × 5; Type 5 × 80	Erect (Intermediate) and short.	Crowded	Yellow with faint red veins on dorsal side of standard	Green with black streaks	Pinkish silver-white with brown markings (patches)

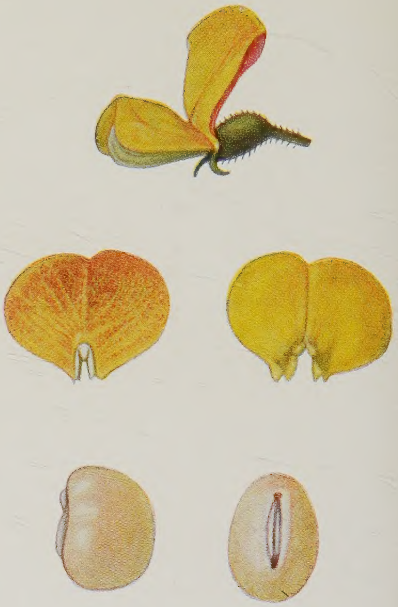
The characters selected for study were those relating to the habit, inflorescence, flower and seed. In F_1 the erect and short habit of Type 5 was dominant over the tall and spreading habit of Type 80, the erectness being partially dominant.

PLATE XXIII.

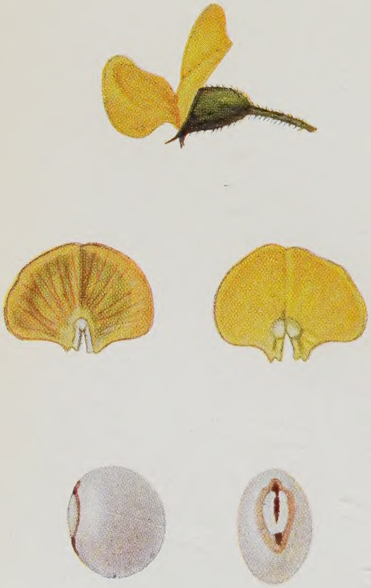
FLOWER AND SEED COLOURS IN PIGEON-PEAS – TYPE 5 × TYPE 80 – F_2



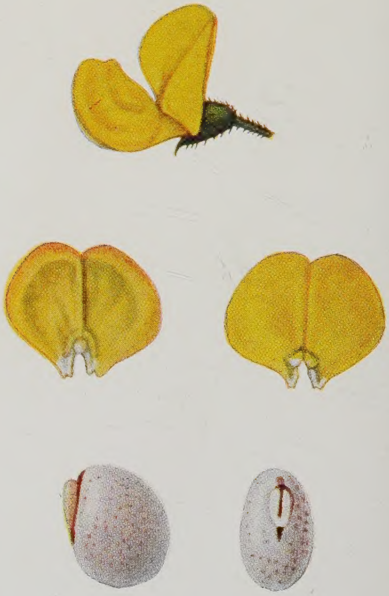
1
Type 5 parent



2
Type 80 parent



3
Type 5 × Type 80 — F_1



4
Ringed flower and Type 1 seed

Similarly the crowded inflorescence of Type 5 was dominant over the open inflorescence of Type 80. The seed of the F_1 resembled that of Type 5 in having silver-white background but possessed faint brown markings like that of Type 80. The flower of F_1, however, was a new phenotype unlike either parent, possessing red colour restricted to the veins on the dorsal side of the standard.

Crossing was easy when Type 80 was the female parent but was more difficult when Type 5 was the female parent.

THE F_2 GENERATION

It is convenient to describe first the inheritance of characters in this generation in the population which was grown in a non-infected field. The frequencies of phenotypes in this normal population can then be contrasted with those in the infected area.

(*1*) *Flower colour*

The F_1 had a yellow flower with faint red veins on the dorsal side of the standard. In F_2 both parental types and the F_1 type were realised and a fourth new phenotype appeared as the recessive (Plate XXIII). This latter type is called " ringed " and is characterised by the possession of red dots on the margin of the dorsal side of the standard, in other respects this flower resembled that of Type 5. The frequencies of these phenotypes in F_2 are shown in Table II.

TABLE II

Segregation in F_2 for flower colour

	F_1	Type 5	Type 80	Ringed	Total
Type 80 × Type 5.	Observed 457 .	152	146	59	814
	Expected 458·1 . (9 : 3 : 3 : 1)	152·7	152·7	50·9	814·4
			$\chi^2=1·6$,	$P=0·66$	
Type 5 × Type 80.	Observed 487 .	164	180	53	884
	Expected 497·25. (9 : 3 : 3 : 1)	165·75	165·75	55·25	884
			$\chi^2=1·5$,	$P=0·67$	

A dihybrid segregation, 9 : 3 : 3 : 1, is indicated and the fit is close, $P=0·66$

(2) *Inflorescence*

Type 5 has a "crowded" inflorescence, with short internodes and flowers in clusters, and Type 80 has an open inflorescence. In F_1 the inflorescence was crowded (Plate XXIV, fig. 1) and in F_2 the following segregation was observed :—

TABLE III

Segregation in F_2 for inflorescence character

		Crowded	Open	Total
Type 80 × Type 5	Observed	609	211	820
	Expected (3 : 1)	615	205	820
		Deviation = 6		S. E. = 12·32
		$\frac{\text{Dev.}}{\text{S.E.}} = \frac{6}{12\cdot32} = 0\cdot49$		
Type 5 × Type 80	Observed	661	222	883
	Expected (3 : 1)	662·25	220·75	883
		Deviation = 1·25		S. E. = 12·87
		$\frac{\text{Dev.}}{\text{S.E.}} = \frac{1\cdot25}{12\cdot87} = 0\cdot097$		

The 'crowded' character is dominant in F_1 and F_2 segregation takes place on a 3 : 1 ratio.

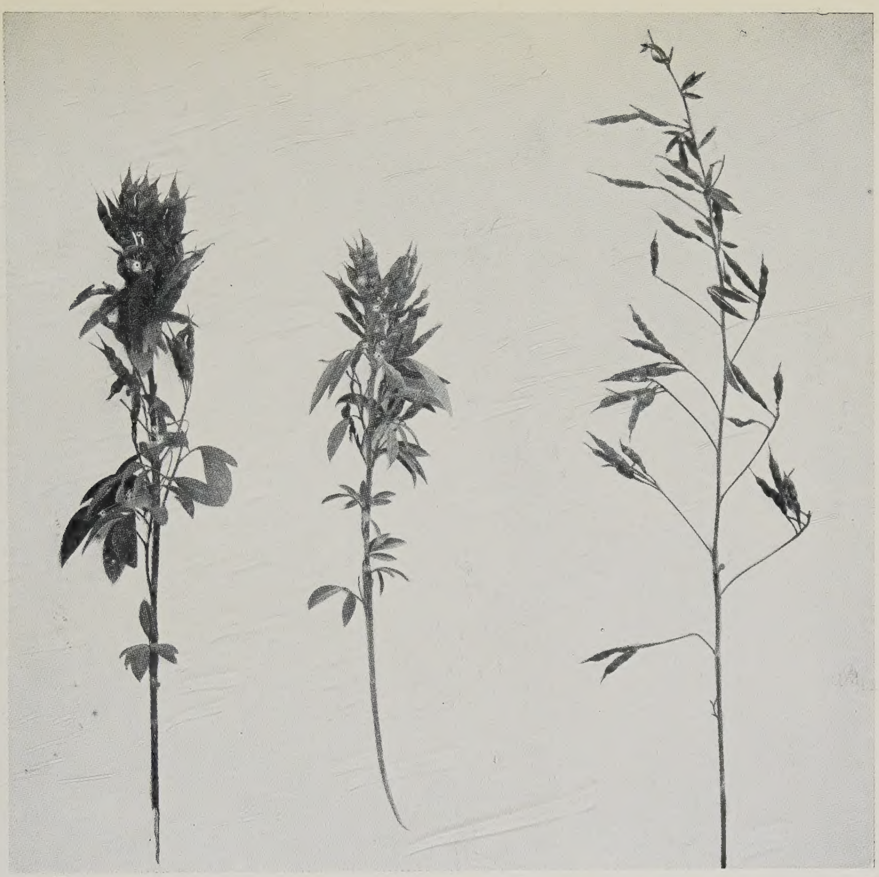


FIG. 1 Types of inflorescence

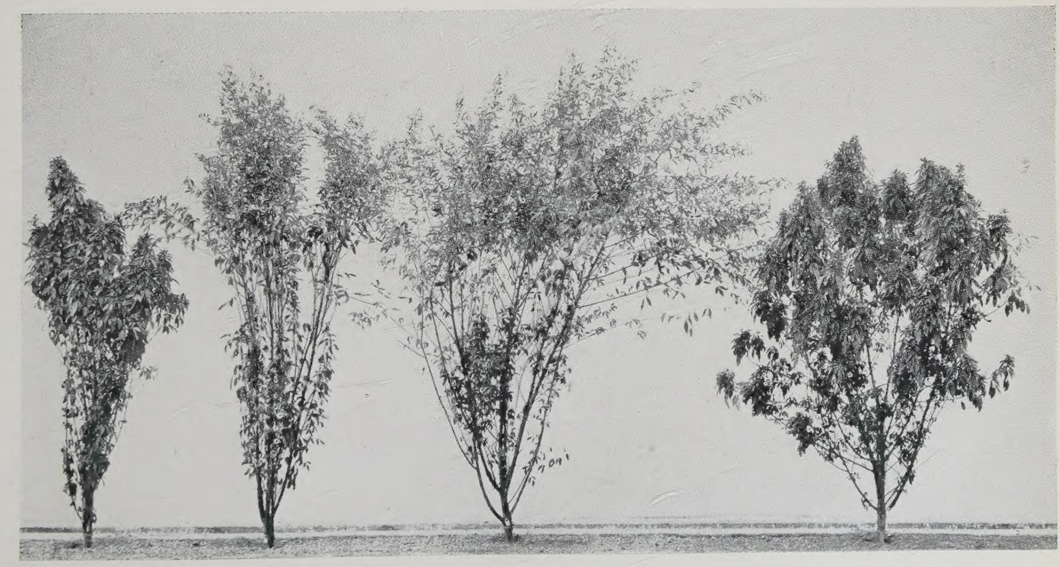


FIG. 2 Plant habit and types of inflorescence :

a. Erect plant with crowded inflorescence.
b. Erect plant with open inflorescence.
c. Spreading plant with open inflorescence.
d. Spreading plants with crowded inflorescence.

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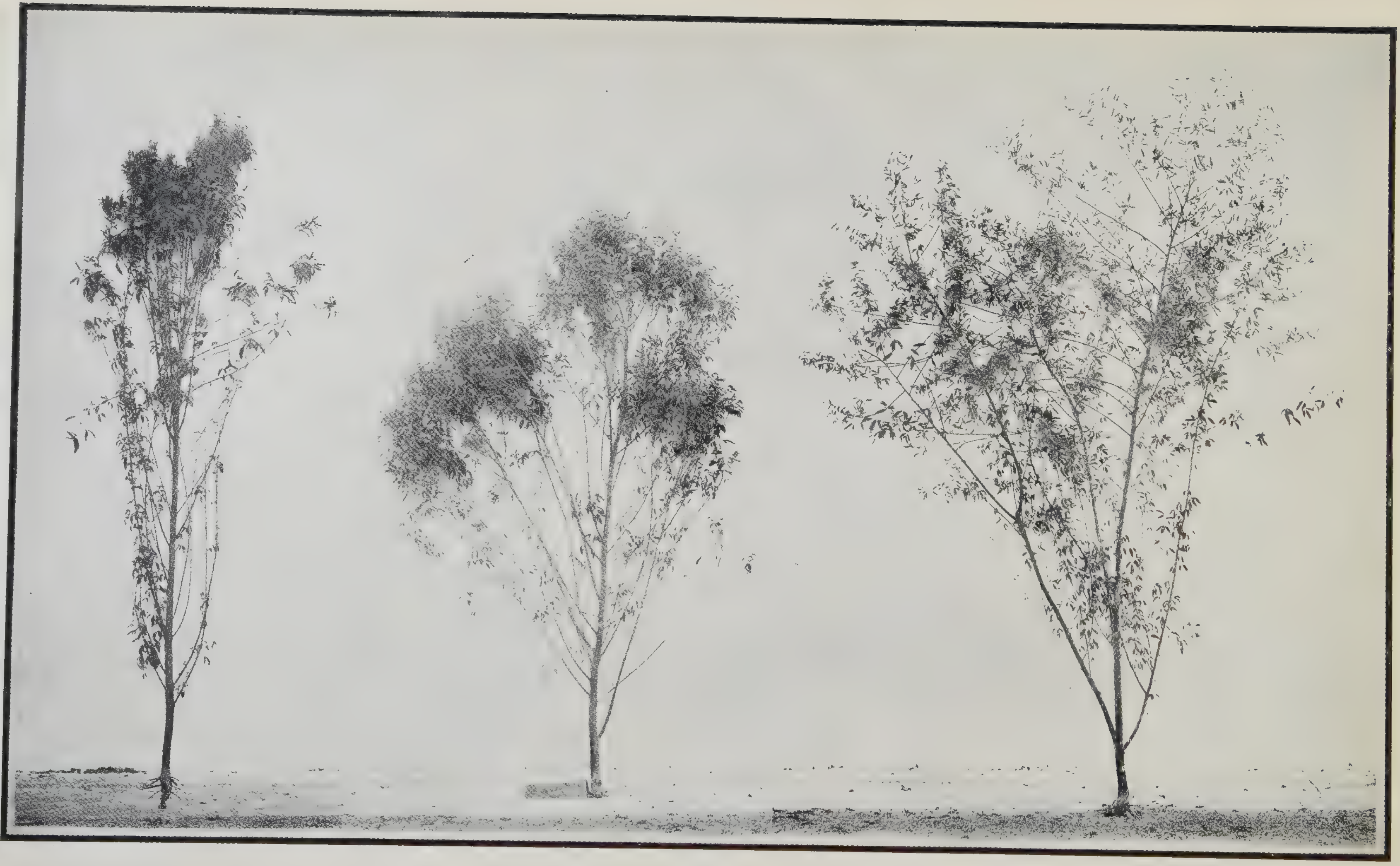


Plant habit (Type 80 × Type 5)

(3) *Habit*

The plant habit of Type 5 was erect, that of Type 80 was spreading and in F_1 the erect habit showed incomplete dominance, the plants of F_1 being less erect than Type 5. It was impossible however in F_2 to separate with any certainty the F_1 and Type 5 phenotypes ; they are therefore classified together.

TABLE IV

Segregation in F_2 for habit

		Erect and Inter-mediate	Spreading	Total
Type 80 × Type 5	Observed	601	231	832
	Expected (3 : 1)	624	208	832
		Deviation = 23		S. E. = 12·49
			$\frac{\text{Dev.}}{\text{S. E.}} = \frac{23}{12 \cdot 49} = 1 \cdot 84$	
Type 5 × Type 80	Observed	644	217	861
	Expected (3 : 1)	645·75	215·25	861
	Deviation = 1·75		S. E. = 12·70	
			$\frac{\text{Dev.}}{\text{S. E.}} = \frac{1 \cdot 75}{12 \cdot 70} = 0 \cdot 14$	

A single-factor difference for plant habit is indicated. The classification of phetontypes is somewhat difficult as the habit of the plant is influenced by the spacing in the field.

(4) *Stature*

In regard to stature, in the experiment of 1929-30, Type 5 had a mean height of 251 cm. with a range of 220-275 cm. Type 80 had a mean height of 320 cm. with a range of 285-345 cm. F_1 (T. 5 × T. 80) showed a mean of 255 cm. and F_1 (T. 80 × T. 5) a mean of 270 cm. The F_2 had a mean of 276 cm. with a range of 205-375 cm. The similarity of the mean and range of the frequency distribution in F_1 with that of Type 5, the shorter parent (Table VII) suggests that short stature is dominant and indeed if we take a height of 290 cm. as the upper limit of dwarfness we can classify F_2 thus :—

TABLE V

Segregation in F_2 for stature of plants in 1929-30

		Short	Tall	Total
Type 80 × Type 5	Observed	561	214	775
	Expected (3 : 1)	581·25	193·75	775

Dev. = 20·25 S. E. 12·05

$$\frac{\text{Dev.}}{\text{S. E.}} = \frac{20\cdot25}{12\cdot05} = 1\cdot68$$

The reciprocal cross (Type 5 × Type 80) was grown again two years later (1932-33) and in this season both parents grew taller, the conditions for growth being more favourable than in the previous season. The mean of Type 5 was 285 cm. with a range of 255-315 cm. and the mean of Type 80 was 352 cm. with a range of 305-375 cm. The mean of F_1 was 290 cm. with a range of 215-325 cm. The mean of F_2 in this year was 322 cm. with a range of 215-395 cm. The mean of F_2 in 1932-33 was therefore 46 cm. higher than in the earlier season and we have taken the upper limit of dwarfness in this season as 340 cm., *i.e.*, 50 cm. above the limit of 290 cm. used in the cross, Type 80 × Type 5.

Classifying the F_2 of the cross, Type 5 × Type 80 on this basis we obtain—

TABLE VI

Segregation in F_2 for stature in 1932-33

		Short	Tall	Total
Type 5 × Type 80	Observed	670	206	876
	Expected (3 : 1)	657	219	876

Dev. = 13 S. E. = 12·82

$$\frac{\text{Dev.}}{\text{S. E.}} = \frac{13}{12.82} = 1\cdot014$$

An examination of the F_2 frequency arrays, however, does not support this hypotheis of a monofactorial difference between tall and short. The F_2 arrays are fairly smooth curves and show no evidence of a natural division at the points at which demarcation should occur on this theory, but the evidence of linkage and the segregations in F_3 tend to support the monofactorial theory of the inheritance of height.

TABLE VII

Frequency distribution of plant height

Name of culture	Year	Plot	Height in centimeters																				Population	Mean	S. E. (N)	σ
			205	215	225	235	245	255	265	275	285	295	305	315	325	335	345	355	365	375	385	395				
Type 5 parent	1929-30	Orchard 4B			4	2	2	7	7	1													23	251·02	3·21	15·26
Type 80 parent	1929-30	Orchard 4B									1	2	2	2	3	3	3						16	320·62	4·72	18·70
(80 × 5) F_1	1929-30	Orchard 4B				1	2	5	1	2													11	255·91	3·55	11·64
(5 × 80) F_1 .	1929-30	Orchard 4B				1	1	2	1	7	4												16	270·00	3·69	14·58
(80 × 5) F_2 .	1929-30	Orchard 4B	4	4	17	45	76	101	132	107	75	44	29	37	46	28	21	4	3	2	...	...	775	276·85	1·14	31·46
(5 × 80) F_2 .	1932-33	N. T. G. 3	...	3	1	5	2	7	8	17	26	66	118	157	168	92	71	50	41	32	11	1	876	322·70	0·93	27·04
Type 5 parent	1932-33	N.T.G. 3						1	5	12	26	19	3	1									67	285·45	1·35	10·98
Type 80 parent	1932-33	N.T.G. 3											1	1	1	5	8	10	15	3			44	352·95	2·34	15·31
F_1	1932-33	N.T.G. 3			1	...	2	1	1	1	2	1	2	4	3								18	290·00	6·36	30·78

If we adopt the monofactorial theory for the inheritance of stature and the two characters of inflorescence and stature are considered together we observe :—

TABLE VIII

Relation of stature and nature of inflorescence in F_2 : Cross Type 80 × Type 5 (1929-30)

	Short Crowded	Tall Crowded	Short Open	Tall Open
Observed	534	36	27	178
Expected on 9 : 3 : 3 : 1 . . .	435·6	145·2	145·2	48·4

$\chi^2=547{\cdot}624$, P =below 0·01

Similarly in the reciprocal cross we observe :—

TABLE IX

Relation of stature and nature of inflorescence in F_2 : Cross Type 5 × Type 80 (1932-33)

	Short Crowded	Tall Crowded	Short Open	Tall Open
Observed	629	33	41	173
Expected	492·75	164·25	164·25	54·75

$\chi^2=490{\cdot}41$, F =below 0·01

Taken separately both characters show a 3 : 1 ratio but combined they depart widely from the expected dihybrid ratio, the frequencies of the parental phenotypes being much increased. Linkage between the short and crowded characters is indicated, with a cross-over value of about 8·5 per cent in Table VIII, and of about 8·8 per cent in Table IX.

Plate XXIV, fig. 2 illustrates that plants with crowded type of inflorescence, whether erect or spreading, are shorter than the plants with the open type of inflorescence.

5. *Seed colour*

The seed of Type 5 is silver-white with faint grey markings and that of Type 80 is fawn with brown markings. The seed of F_1 is pinkish silver-white with brown markings (Plate XXIII). The brown markings are therefore dominant and in F_2 we observe :—

TABLE X

Segregation in F_2 for seed colour

		Seed with brown markings like F_1 or Type 80	Seed like Type 5	Total	Significance
Type 80 × Type 5	Observed .	578	198	776	Dev. = 4·0 S. E. = 12·06
	Expected (3 : 1)	582	194	776	$\frac{\text{Dev.}}{\text{S. E.}} = \mathbf{0 \cdot 33}$
Type 5 × Type 80	Observed .	661	207	868	Dev. = 10·0 S. E. = 12·76
	Expected (3 : 1)	651	217	..	$\frac{\text{Dev.}}{\text{S. E.}} = \mathbf{0 \cdot 78}$

Owing to the wide range of variation in the phenotype with brown markings it was impossible to distinguish with certainty in F_2 the seed phenotype of Type 80 from that of F_1, the Type 5 phenotype, however, could always be clearly recognised. We have, therefore, indicated a monohybrid ratio for seed colour although we strongly suspect that the inheritance of this character is more complicated. Even if the inheritance of seed colour is proved at some future date to be more complicated the main segregation (3 : 1) between Type 5 and others will remain valid and any further elucidation of the position will simply show the type of inheritance of other factors within this framework. Flower colour and seed colour show linkage, brown markings on the seed being linked with the F_1 and Type 80 phenotypes for flower colour. If we classify the F_1 and Type 80 phenotypes together as 'coloured' flowers and the Type 5 and 'Ringed' phenotypes as 'non-coloured' we obtain:—

TABLE XI

Relation of flower and seed colours in F_2

	Coloured flower and coloured seed	Coloured flower and white seed	Non-coloured flower and coloured seed	Non-coloured flower and white seed
Type 80 × Type 5 . .	575	4	3	194
Type 5 × Type 80 . .	652	4	9	203

The cross, Type 80 × Type 5 shows a cross-over value of 0·9 per cent and the reciprocal a value of 1·52 per cent. The evidence of F_3, however, indicates that the linkage is absolute and that seed and flower colour are determined by the same factor or factors.

Theory

We may suppose—

A=factor for red in standard and for brown spotting on seed coat.

B=factor restricting red colour to veins in the standard in the presence of **A** and inibiting red dots in the absence of **A**.

P=factor for erect habit

S=factor for short stature

K=factor for crowded pod habit

Type 5=**aB** (**K S**) **P**.

Type 80=**Ab** (**k s**) **p**.

In flower colour in F_2 we are dealing with a segregation of **A** and **B** which will give—

9 **AB**=F_1 flower with red veins on dorsal side of standard

3 **Ab**=Type 80 flower with red colour diffused over standard

3 **aB**=Type 5 flower—yellow

1 **ab**='ringed flower'

These phenotypes are all realised in the above proportions in F_2.

In seed colour we have a segregation of—

AA=brown markings like Type 80 and fawn background

Aa=faint brown markings and pinkish silver-white background

aa=silver-white like Type 5.

THE F_3 GENERATION

(1) *Flower colour*

The behaviour of cultures in F_3 as regards flower colour is shown in the table below :—

TABLE XII

F_3 behaviour for the inheritance of flower colour

No. of F_3 cultures and nature of their parents in F_2	Flower colour segregation in F_3	Formulae	Frequencies		Seed colour segregation in F_3
			Observ-ed	Expect-ed	
32 F_1 .	Pure F_1 . .	1 AABBCC	2	3·55	Pure "brown markings"
	3 F_1 : one Type 80	2 AABbCC	9	7·1	Do.
	3 F_1 : one Type 5.	2 AaBBCC	5	7·1	3 Brown markings : one silver-white
	9 F_1 : 3 type 80 . 3 Type 5 : one Ringed	4 AaBbCC	16	14·2	Do.
14 Type 80 .	Pure Type 80 .	1 AAbbCC	5	4·66	Pure brown markings
	3 Type 80 : one Ringed	2 AabbCC	9	9·33	3 Brown markings : one silver-white
9 Type 5 .	Pure Type 5 .	1 aaBBCC	1	3·0	Pure Type 5 (silver-white)
	3 Type 5 : one Ringed	2 aaBbCC	8	6·0	Do.
5 Ringed .	Pure ringed .	1 aabbCC	5	5	Do.

Segregation in the F_1 group splitting into 3 F_1 : 1 Type 80 :—

	F_1	Type 80	Total
Observed	471	179	=650
Expected	487·5	162·5	
Deviation	16·5	16·5	

S. E. = 11·04

$$\frac{\text{Dev.}}{\text{S. E.}} = \frac{16 \cdot 5}{11 \cdot 04} = 1 \cdot 49.$$

The fit is good.

Segregation in the F_1 group splitting into 3 F_1 : one Type 5 :—

	F_1	Type 5	Total
Observed	237	90	=327
Expected	245·25	81·75	
Deviation	8·25	8·25	

S. E.=7·83

$$\frac{\text{Dev.}}{\text{S. E.}}=\frac{8\cdot 25}{7\cdot 83}=\mathbf{1\cdot 05}.$$ The fit is good.

Segregation in the F_1 group splitting into 9 F_1 : 3 Type 80 : 3 Type 5 : one Ringed :—

	F_1 :	Type 80 :	Type 5 :	Ringed	Total
Observed	610	204	202	73	=1089
Expected	612·5	204·2	204·2	68·1	
Deviation	2·5	0·2	2·2	4·9	

$\chi^2=0\cdot 386$

P—Between 0·90 and 0·95. The fit is good.

Segregation of the splitting Type 80 :—

	Type 80 :	Ringed	Total
Observed	462	149	=611
Expected	458·25	152·75	
Deviation	3·75	3·75	

S. E.=10·70

$$\frac{\text{Dev.}}{\text{S. E.}}=\frac{3\cdot 75}{10\cdot 70}=\mathbf{0\cdot 35}.$$ The fit is good.

Segregation of the splitting Type 5 group :—

	Type 5 :	Ringed	Total
Observed	405	160	=565
Expected	423·75	141·25	
Deviation	18·75	18·75	

S. E.=10·29

$$\frac{\text{Dev.}}{\text{S. E.}}=\frac{18\cdot 75}{10\cdot 29}=\mathbf{1\cdot 82}.$$ The fit is good.

The nature of the segregations in F_3 and their respective frequencies confirm the dihybrid theory for flower colour. The segregation for seed colour is also shown in Table XII and agrees with the theory previously set out.

(2) *Inflorescence*

TABLE XIII

F_3 behaviour for the inheritance of inflorescence character

No. of F_3 cultures and nature of their parents in F_2	Segregation	Formulae	Frequencies	
			Observed	Expected
44 Crowded . .	Pure crowded . .	**KK**	14	14·66
	3 crowded : 1 open .	**Kk**	30	29·33
16 Open . .	Pure open . .	**kk**	16	16

The segregation in the spliting crowded F_2 plants was :—

	Crowded :	Open	Total
Observed	1586	504	=2090
Expected (3 : 1)	1567·5	522·5	
Deviation	18·5	18·5	

S. E. = 19·80

$$\frac{\text{Dev.}}{\text{S. E.}} = \frac{18 \cdot 50}{19 \cdot 80} = \mathbf{0 \cdot 93}.$$ The fit is good.

The dominance of the 'crowded' habit and its inheritance on a 3 : 1 ratio are confirmed.

(3) *Habit*

Erect and spreading.—Owing to the wide range of variation in the spreading, intermediate and erect phenotypes the observed segregation in F_3 cultures revealed several instances of wrong diagnosis in F_2, but the general result of F_3 confirms our theory as shown in the following table :—

TABLE XIV

F_3 behaviour for the inheritance of habit

No. of F_3 cultures and nature of their parents in F_2	Segregation	Formulae	Frequencies	
			Observed	Expected
15 Erect .	Pure erect . . .	**PP**	15	15
30 Intermediate	1 Erect : 2 Intermediate : 1 Spreading	**Pp**	26	30
	Pure erect . . .	**PP**	1	*Nil*
	Pure spreading . .	**pp**	3	*Nil*
15 Spreading .	Pure spreading . .	**pp**	12	15
	1 Erect : 2 Intermediate : 1 Spreading	**Pp**	3	*Nil*

Thus in F_2 it is evident that one erect and three spreading plants were wrongly included among thirty intermediates and that one intermediate was wrongly classed among fifteen spreading individuals.

The total segregation in the twenty-six splitting intermediates is as follows :—

	Observed	Calculated on 1 : 2 : 1 ratio
Erects	447	434·25
Intermediates	888	868·50
Spreading	402	434·25
Total .	1737	

$\chi^2 = 3\cdot 22$

P—between 0·1 and 0·2

4. Stature

In F_3 forty cultures were grown from plants which had been classed as 'short' in F_2 and twenty cultures from plants which had been classed as 'tall'. The nature of the segregations is summarised below :—

TABLE XV

F_3 behaviour of the inheritance of stature

No. of F_3 cultures and nature of their parents in F_2	Segregations in F_3	Frequencies	
		Observed	Expected
40 Short . . .	Pure short	13	13·3
	Segregating	26	26·6
	Pure tall	1	*Nil*
20 Tall . . .	Pure tall	15	20
	Segregating	4	*Nil*
	Pure short	1	*Nil*

The occurrence of segregating cultures in F_3 from parents which were classed as the double recessive tall phenotype in F_2 is to be expected as some cases of wrong diagnosis must occur in classifying a quantitative character such as this in which there is an overlap between the upper and lower limits of the two phenotypes and in which variations in soil fertility will have a marked influence on the development of phenotypes.

The F_2 generation showed strong linkage between short stature (factor **S**) and crowded inflorescence (factor **K**). The cross-over value was calculated at 8·5 per cent and on this basis we conclude that the F_1 produced gametes in the ratio of 45·75 **SK** : 4·25 **Sk** : 4·25 **sK** : 45·75 **sk**. The F_2 from these gametes should form the different genotypes as noted below :—

Genotype	Frequencies		Remarks
SSKK . .	2093·06	Crowded short 7093·06	The ratio of crowded to open is 3 : 1 and similarly of short plants to talls is 3 : 1. The ratio of the four phenotypes is about 17·3 : 1 : 1 : 5·8 which agrees fairly closely with the observation.
SsKK . .	388·88		
SSKk . .	388·88		
SsKk . .	4222·24		
ssKK . .	18·06	Crowded tall 406·94	
ssKk . .	388·88		
SSkk . . .	18·06	Open short 406·94	
Sskk . . .	388·88		
sskk . . .	2093·06	Open tall 2093·06	
	10,000·00		

In our F_3 population of sixty cultures the observed and expected values were as shown in Table XVI below.

TABLE XVI

Relationship of habit and stature in F_3

No. of F_3 cultures and nature of parents in F_2	Segregation in F_3					
	Habit			Stature		
	Nature of segregation	Frequencies		Nature of segregation	Frequencies	
		Observed	Expected		Observed	Expected
39 crowded short plants	Pure crowded . .	13	13	Pure short . .	12	11
				3 short : one tall .	1	2
	3 crowded : one open	26	26	Pure short . .	1	2·2
				3 short : one tall .	25	23·8
15 open tall . .	Pure open . .	15	15	Pure tall . .	15	15
5 crowded tall . .	Pure crowded .	1	1·67	Pure tall . .	*Nil*	5
	3 crowded : one open	4	3·33	Pure short . .	1	*Nil*
				3 short : one tall .	4	*Nil*
1 open short . .	Pure open . .	1	1	Pure tall . .	1	*Nil*

It will be observed that in the cross-over classes 'crowded, tall' and 'open, short' the behaviour in F_3 shows that the parent was wrongly diagnosed in F_2. Does this really mean that the linkage is absolute and that the supposed cross-overs are in all cases due to wrong diagnosis of stature ?

In Table XVII the five plants Nos. 51, 473, 413, 582 and 141 classed as 'crowded, tall' in F_2 had heights of 341, 342, 344, 344 and 357 cm. respectively, and the first four heights are very close to the upper limit of dwarfness. The one plant No. 715 classed in "open, short" had a height of 326 cm.—this should place it definitely among shorts. Table XVII shows the relationship of the nature of inflorescence and plant height in the F_3 cultures. It will be evident that the average height in cultures pure for crowded inflorescence is less than that in cultures which are pure for open type of inflorescence. Similarly in Table XVIII the distribution of plants with crowded inflorescence has definitely a lower range for stature than plants in the same culture which possessed the open type of inflorescence.

TABLE

Relation of nature of inflorescence and

Nature of inflorescence	Culture No.	Height of the parent plant in F_2	Frequency distribution of plant height													
			155	165	175	185	195	205	215	225	235	245	255	265	275	285
Pure crowded	T. 5 parent on the east side of F_3		1	6	12	12	9	2	4	6	4	2	5	2	...	...
Do. .	F_3 No. 46 .	316 short .	1	5	5	7	11	5	5	4	5	2	2	3	3	...
Do. .	„ 99 .	324 „ .		1	1	3	14	6	10	10	7	...	6	2	1	...
Do. .	„ 139 .	327 „ .				1	12	11	16	7	2	4	...	...	...	1
Do. .	„ 186 .	322 „ .			1	1	12	11	15	10	3	2	1	1	...	...
Do. .	„ 199 .	325 „ .					1	3	13	14	11	11	11	4	1	...
Do. .	„ 261 .	328 „ .					4	9	6	10	7	8	8	4	2	...
Do. .	„ 266 .	322 „ .				2	2	7	17	10	10	11	3	4	...	...
Do. .	„ 405 .	329 „ .				1	1	3	6	14	18	13	6	1	2	...
Do. .	„ 533 .	317 „ .			1	2	7	3	8	15	16	12	4	1	...	...
Do. .	„ 580 .	314 „ .				6	6	8	22	19	10	...	...	...	...	...
Do. .	„ 582 .	344 Tall .		1	...	...	2	2	6	12	18	19	11	2	1	...
Do. .	„ 627 .	339 Short .					2	1	2	2	12	23	15	10	1	...
Do. .	„ 670 .	329 „ .					1	...	13	...	24	10	7	2	...	...
Do. .	„ 914 .	304 „ .					1	1	2	6	9	16	12	14	7	2
Do. .	T. 5 (on the west side of F_3)								2	4	14	14	10	9	...	...
Pure open .	T. 80 (on the east side of F_3)							3	5	7	9	5	8	3	5	6
Do. .	F_3 No. 143 .	366 Tall .							3	4	9	4	7	11	9	[illegible]
Do. .	„ 222 .	350 „ .								3	9	10	8	5	7	6
Do. .	„ 268 .	345 „ .						1	—	2	9	10	7	6	9	15
Do. .	„ 269 .	345 „ .								3	6	4	12	5	12	10
Do. .	„ 319 .	349 „ .						3	4	2	4	7	6	5	14	5
Do. .	„ 414 .	341 „ .									2	1	12	7	12	11
Do. .	„ 475 .	385 „ .							1	1	2	7	7	9	17	7
Do. .	„ 679 .	380 „ .									1	3	6	11	13	23
Do. .	„ 715 .	326 Short .									3	3	8	11	10	[illegible]
Do. .	„ 722 .	348 Tall .								1	1	2	10	14	16	10
Do. .	„ 723 .	363 „ .									1	...	6	4	11	13
Do. .	„ 858 .	352 „ .									2	3	5	6	13	11
Do. .	„ 917 .	378 „ .							1	...	...	1	3	9	14	14
Do. .	„ 962 .	378 „ .										2	4	9	15	9
Do. .	„ 963 .	351 „ .											1	2	11	8
Do. .	„ 1007	360 „ .											2	3	6	9
Do. .	T. 80 (on the west of F_3)												2	5	10	19

XVII

plant height in F_3 (T. 5 × T. 80).

in cm.					Total population	Average height in cm.	σ	C. V.	Lines away from parent line on the east	Calculated height of the parent cm.	Remarks
295	305	315	325	335							
...	...	...	...	...	65	201·1±3·72	29·7	14·7	0		Lines of cultures run north to south, and are 4 ft. apart from one another. There is a fertility gradient from east to west, the western side being richer than the eastern. This is shown by the increase in height in both the parents, on the western side, the parental rows having been put both on the eastern and western sides of the F_3.
...	...	...	...	...	58	208·4±4·29	32·5	15·6	1		
...	...	...	...	...	61	216·9±3·06	23·8	10·9	3		
...	...	...	...	...	54	213·5±2·30	16·7	7·8	4		
...	...	...	...	...	57	213·1±2·36	17·6	8·2	9		
...	...	...	...	...	69	234·4±2·27	18·7	7·9	10	208 T. 5	
...	...	...	...	...	58	231·4±2·99	22·6	9·7	12		T. 5 T. 80
...	...	...	...	...	66	226·8±2·31	18·7	8·2	14		Height on the east side . .. . 201·1 246·7
...	...	...	...	...	65	233·8±2·01	16·1	6·8	27	219 T. 5	Height on the west side . . 243·3 288·8
...	...	...	...	...	69	226·2±2·39	19·7	8·7	39	228 T. 5	Increase in height . 42·2 42·1
...	...	...	...	...	71	215·1±1·71	14·3	6·6	41		
...	...	...	...	...	74	235·8±2·03	17·3	7·3	42		
...	...	...	...	...	68	245·3±1·92	15·8	6·4	43		
...	...	...	...	...	57	235·0±1·58	14·8	6·3	45	232 T. 5	
...	...	...	...	...	68	251·2±2·07	16·9	6·3	53	238 T. 5	Segregating for height.
...	...	...	...	...	55	243·3±2·15	15·7	6·4	62		
...	1	...	...	...	52	246·7±3·48	25·0	10·1	From east)	T. 80 (on	
6	2	3	1	...	64	263·9±3·39	27·1	10·2	7	251 T. 80	
8	5	1	2	...	64	267·0±3·35	26·6	9·9	12		
9	...	...	...	...	68	264·7±2·78	22·6	8·5	17	258 T. 80	
8	3	3	...	...	66	270·0±2·90	23·4	8·7	18		
11	6	1	...	...	68	266·2±3·80	31·0	11·6	24	262 T. 80	
7	6	1	...	...	59	275·8±2·48	18·7	6·8	32		
13	...	5	...	1	70	274·4±2·78	23·0	8·3	36	271 T. 80	
13	5	...	...	...	75	278·7±1·86	15·9	5·7	47	278 T. 80	
8	5	1	...	...	56	273·9±2·69	19·7	7·2	48		
8	3	2	...	...	67	274·1±2·21	17·9	6·5	49		
13	7	5	3	...	63	286·9±2·54	19·4	6·7	50		
14	8	1	...	...	63	280·4±2·37	18·7	6·6	52		
17	10	...	...	...	69	282·8±2·06	16·9	5·9	55	284 T. 80	
9	8	8	...	...	64	284·3±2·42	19·2	6·7	57		
10	9	5	3	...	49	292·5±2·06	16·9	5·8	58		
13	11	11	4	1	60	296·8±2·37	18·2	6·1	61		
16	12	4			68	288·8±1·74	14·2	4·9	62		

TABLE

Plant height in the F_3 cultures that are segre-

Culture No.	Height of the parent plant in F_2 cm.	Frequency distribution of height in															
		155	165	175	185	195	205	215	225	235	245	255	265	275	285	295	305
T. 5 parent on the east side of F_3.		1	6	12	12	9	2	4	6	4	2	5	2	...	...	...	...
T. 80 parent on the east side of F_3.		...	...	...	...	...	3	5	7	9	5	8	3	5	6	...	1
F_2 No. 51	341 Tall	...	...	1	5	14	9	9	8	8	4	9	2	4	...	2	1
,, 141	357 ,,	...	...	1	...	1	4	4	15	14	6	7	4	3	...	3	2
,, 148	332 Short	...	...	...	...	2	3	7	15	9	8	8	11	3	4	1	1
,, 185	332 ,,	...	...	...	...	2	6	7	12	12	10	2	8	4	4	2	...
,, 263	318 ,,	...	...	...	...	5	7	6	12	13	11	7	6	1	...	2	1
,, 267	299 ,,	...	...	...	...	1	2	12	12	11	6	4	6	4	5	2	1
,, 272	317 ,,	...	...	...	3	...	3	4	6	12	10	10	4	4	8	2	2
,, 308	323 ,,	...	...	...	...	...	3	9	12	12	10	7	8	2	1	6	2
,, 310	304 ,,	...	...	...	...	1	5	9	9	12	5	7	2	2	1	5	1
,, 311	329 ,,	...	...	...	...	1	2	6	10	13	9	9	4	6	1	1	...
,, 314	315 ,,	...	...	...	1	1	2	5	6	14	13	5	4	2	4	3	...
,, 355	305 ,,	...	...	...	...	4	8	10	9	9	7	5	7	3	3	3	...
,, 365	320 ,,	...	...	...	...	3	3	5	14	11	11	4	6	...	1	...	2
,, 366	334 ,,	...	...	...	1	3	3	6	16	18	8	6	4	1	2	1	...
,, 410	324 ,,	...	...	...	...	4	2	6	11	14	11	6	1	2	3	4	3
,, 412	337 ,,	...	...	...	...	...	3	7	17	11	20	5	2	6	2	2	2
,, 413	344 Tall	...	...	...	...	1	1	2	8	6	13	17	9	4	1	4	3
,, 436	323 Short	...	...	2	1	4	6	7	7	10	13	4	9	2	2	4	...
,, 437	322 ,,	...	...	...	...	2	3	3	7	9	17	6	3	2	9	4	1
,, 473	342 Tall	...	...	...	...	2	1	6	9	6	17	14	3	4	4	2	1
,, 476	333 Short	...	...	2	...	1	7	7	7	13	12	11	1	7	...	1	...
,, 478	308 ,,	...	...	...	3	4	4	18	12	1	7	6	1	1	1	2	1
,, 485	327 ,,	...	...	...	...	4	4	4	13	9	6	5	2	...	...	...	...
,, 574	318 ,,	...	...	2	...	2	4	9	13	21	11	2	2	3	1	...	...
,, 669	336 ,,	...	...	...	...	...	2	1	3	11	20	15	7	4	3	3	...
,, 724	327 ,,	...	...	...	...	...	...	...	...	10	20	10	12	7	5	3	1
,, 908	312 ,,	...	...	...	...	...	2	1	3	6	9	10	12	15	4	...	...
,, 918	322 ,,	...	...	...	...	...	...	4	1	12	7	17	11	10	2	4	...
,, 964	327 ,,	...	...	...	...	2	...	3	...	11	14	10	15	9	5	3	...
,, 1006	322 ,,	...	...	...	...	2	2	...	7	3	9	20	13	6	7	1	...
T. 5 on the west side of F_3.		...	...	...	...	1	1	2	4	14	14	10	9	...	...	...	...
T. 80 on the west side of F_3.		...	...	...	...	...	...	...	...	...	...	2	5	10	19	16	12

XVII—*contd.*

gating for the nature of inflorescence

cm.				Total population	Average	σ	C. V.	Lines away from the parents	Remarks
315	325	335	345						
...	...	...	...	65	201·1±3·72	29·7	14·7		
...	...	...	...	52	246·7±3·48	25·0	10·1		
...	...	...	...	76	224·9±3·42	29·7	13·2	2	
...	...	...	...	64	239·8±3·26	25·9	10·8	5	
...	...	...	...	72	242·7±2·91	24·6	10·1	7	
...	1	...	1	71	242·6±3·50	29·2	12·0	8	
...	1	...	...	72	236·4±3·08	26·0	11·0	13	
...	...	...	...	66	242·0±3·21	26·0	10·7	15	
2	1	1	...	72	251·8±3·69	31·3	12·4	18	
1	...	...	...	73	245·9±3·18	27·1	10·9	19	
...	...	...	...	59	239·9±3·53	27·0	11·2	20	
...	...	...	...	62	241·8±2·67	21·1	8·7	21	
...	...	...	...	60	243·3±3·17	24·3	10·0	22	
1	...	...	...	69	238·2±3·45	28·5	11·9	24	
...	...	...	...	60	236·8±2·96	22·8	9·6	25	
...	...	...	...	69	234·7±2·57	21·2	9·0	26	
...	...	...	...	67	242·3±3·44	27·9	11·1	28	
1	...	...	...	78	243·2±2·76	24·2	9·9	29	
...	...	...	...	69	252·5±2·81	23·2	9·2	30	
...	...	...	...	71	237·5±3·42	28·7	12·1	32	
...	...	...	...	66	248·9±3·30	26·7	10·7	33	
...	...	...	...	69	246·1±2·82	23·4	9·5	34	
...	...	...	...	69	236·9±2·90	23·9	10·0	36	
...	...	...	...	61	228·3±3·42	26·6	11·6	37	
...	...	...	...	47	229·2±2·69	18·4	8·0	38	Pure short.
...	...	...	...	70	231·4±2·46	20·4	8·8	40	
...	...	...	...	69	250·8±2·27	18·7	7·4	44	
...	...	...	...	68	257·6±2·16	17·7	6·8	50	
...	...	...	...	62	256·6±2·48	19·4	7·6	52	
...	...	...	...	68	255·4±2·39	19·7	7·7	55	
...	...	...	...	72	255·0±2·51	21·1	8·3	58	
...	...	...	...	70	253·9±2·57	21·3	8·4	61	
...	...	...	...	55	243·3±2·15	15·7	6·4	62	
4	...	...	...	68	288·8±1·74	14·2	4·9	62	

TABLE XVIII

Frequency distribution of plant height in F_3 cultures segregating for the nature of inflorescence

(The distribution in the open and crowded classes are given separately. The frequencies of the plants havin crowded pod habit are printed in *italics*.)

F_3 culture No.	Height of the parent plant in F_2 (cm.)	Frequencies under different classes of plant height in cm.																		Total population	Remarks
		175	185	195	205	215	225	235	245	255	265	275	285	295	305	315	325	335	345		
51	341 Tall	*1*	*4*	*12*	*7*	*3*	*5*	*6*	*3*	*4*	*2*	*3*	..	..	..	..	..	..	..	*50*	
		..	1	2	2	6	3	2	1	5	..	1	..	2	1	..	..	..	..	26	
141	357 ,,	*1*	..	*1*	*4*	*4*	*15*	*12*	*4*	*5*	*2*	*2*	..	*3*	*1*	..	..	..	..	*54*	
		..	..	..	..	..	..	2	2	2	2	1	..	..	1	..	..	..	..	10	
148	332 Short	..	..	*2*	*3*	*7*	*14*	*7*	*5*	*7*	*8*	*2*	*2*	..	..	..	..	..	..	*57*	
		..	..	..	..	..	1	2	3	1	3	1	2	1	1	..	..	..	..	15	
185	332 ,,	..	..	*2*	*6*	*6*	*12*	*9*	*8*	*1*	*4*	*2*	*2*	..	..	..	..	..	..	*52*	
		..	..	..	..	1	..	3	2	1	4	2	2	2	..	..	1	..	1	19	
263	318 ,,	..	..	*5*	*7*	*6*	*11*	*11*	*10*	*6*	*5*	..	..	..	..	..	..	..	..	*61*	
		..	..	..	..	..	1	2	1	1	1	1	..	2	1	..	1	..	..	11	

267	299 ,,	..	..	*1*	*2*	*12*	*12*	*10*	*6*	*2*	*5*	*2*	..	..	..	..	..	..	..	*52*
		..	..	..	..	..	..	1	..	2	1	2	5	2	1	..	..	..	..	14
272	317 ,,	..	*3*	..	*3*	*4*	*6*	*10*	*8*	*5*	*3*	*1*	..	..	..	..	..	..	..	*43*
		..	..	..	..	..	..	2	2	5	1	3	8	2	2	2	1	1	..	29
308	323 ,,	..	..	..	*3*	*9*	*11*	*9*	*9*	*5*	*6*	*2*	..	*3*	..	..	..	..	..	*57*
		..	..	..	..	..	1	3	1	2	2	..	1	3	2	1	..	..	..	16
310	304 ,,	..	..	*1*	*5*	*9*	*9*	*9*	*3*	*2*	*1*	..	..	..	..	..	..	..	..	*39*
		..	..	..	..	..	..	3	2	5	1	2	1	5	1	..	..	..	..	20
311	329 ,,	..	..	*1*	*2*	*6*	*10*	*13*	*7*	*6*	*4*	*3*	..	..	..	..	..	..	..	*52*
		..	..	..	..	..	..	..	2	3	..	3	1	1	..	..	..	..	..	10
314	315 ,,	..	*1*	*1*	*2*	*5*	*5*	*14*	*13*	*5*	*2*	..	..	*1*	..	..	..	..	..	*49*
		..	..	..	..	..	1	..	..	..	2	2	4	2	..	..	..	..	..	11
355	305 ,,	..	..	*4*	*7*	*10*	*9*	*7*	*7*	*1*	*1*	*1*	..	..	..	..	..	..	..	*47*
		..	..	..	1	..	..	2	..	4	6	2	3	3	..	1	..	..	..	22
365	320 ,,	..	..	*3*	*3*	*5*	*13*	*10*	*10*	*2*	*2*	..	..	..	..	..	..	..	..	*48*
		..	..	..	..	..	1	1	1	2	4	..	1	..	2	..	..	..	..	12
366	334 ,,	..	*1*	*3*	*3*	*6*	*15*	*17*	*8*	*4*	..	..	..	..	..	..	..	..	..	*57*
		..	..	..	..	..	1	1	..	2	4	1	2	1	..	..	..	..	..	12

F_3 culture No.	Height of the parent plant in F_2 (cm.)	Frequencies under different classes of plant height in cm.																		Total population	Remarks.
		175	185	195	205	215	225	235	245	255	265	275	285	295	305	315	325	335	345		
410	324 Short	..	..	*4*	*2*	*6*	*11*	*13*	*10*	*3*	..	..	..	..	..	..	..	..	..	*49*	
		..	..	..	..	..	..	1	1	3	1	2	3	4	3	..	..	..	..	18	
412	337 „	..	..	..	*3*	*7*	*17*	*11*	*20*	*4*	*2*	..	..	..	..	..	..	..	..	*64*	
		..	..	..	..	..	..	..	..	1	..	6	2	2	2	1	..	..	..	14	
413	344 Tall	..	..	*1*	*1*	*2*	*8*	*3*	*10*	*15*	*6*	..	..	..	..	..	..	..	..	*46*	
		..	..	..	..	..	..	3	3	2	3	4	1	4	3	..	..	..	..	23	
436	323 Short	*2*	*1*	*4*	*6*	*7*	*7*	*9*	*12*	*4*	*5*	..	..	..	..	..	..	..	..	*57*	
		..	..	..	..	..	..	1	1	..	4	2	2	4	..	..	..	..	..	14	
437	322 „	..	..	*2*	*3*	*3*	*7*	*9*	*16*	*3*	..	..	..	..	..	..	..	..	..	*43*	
		..	..	..	..	..	..	..	1	3	3	2	9	4	1	..	..	..	..	23	
473	342 Tall	..	..	*1*	*1*	*6*	*8*	*6*	*11*	*7*	*1*	*1*	*1*	..	..	..	..	..	..	*43*	
		..	..	1	..	..	1	..	6	7	2	3	3	2	1	..	..	..	..	26	
476	333 Short	*2*	..	*1*	*6*	*7*	*7*	*12*	*10*	*7*	..	..	..	..	..	..	..	..	..	*52*	
		..	..	..	1	..	..	1	2	4	1	7	..	1	..	..	..	..	..	17	
478	308 „	..	*3*	*4*	*4*	*18*	*12*	..	*5*	*5*	*1*	..	..	..	..	..	..	..	..	*52*	
		..	..	..	..	..	..	1	2	1	..	1	1	2	1	..	..	..	..	9	
485	327 „	..	..	*4*	*4*	*4*	*11*	*8*	*3*	*3*	*2*	..	..	..	..	..	..	..	..	*39*	Pure short.
		..	..	..	..	..	2	1	3	2	..	..	..	..	..	..	..	..	..	8	

574	318	,,	*2*	..	*2*	*4*	*8*	*11*	*14*	*10*	..	*1*	..	..	..	..	..	..	..	..	*52*
			..	..	..	..	1	2	7	1	2	1	3	1	..	..	..	..	..	..	18
669	336	,,	..	..	..	*2*	*1*	*3*	*11*	*19*	*14*	*7*	*2*	*1*	..	..	..	..	..	..	*60*
			..	..	..	..	..	..	..	1	1	..	2	2	3	..	..	..	..	..	9
724	327	,,	..	..	..	..	..	..	*10*	*17*	*7*	*9*	*5*	*2*	..	..	..	..	..	..	*50*
			..	..	..	..	..	..	..	3	3	3	2	3	3	1	..	..	..	..	18
908	312	,,	..	..	..	*2*	*1*	*3*	*6*	*7*	*8*	*11*	*13*	*2*	..	..	..	..	..	..	*53*
			..	..	..	..	..	..	..	2	2	1	2	2	..	..	..	..	..	..	9
918	322	,,	..	..	..	..	*4*	*1*	*11*	*7*	*10*	*10*	*5*	..	..	..	..	..	..	..	*48*
			..	..	..	..	..	..	1	..	7	1	5	2	4	..	..	..	..	..	20
964	327	,,	..	..	*2*	..	*3*	..	*10*	*11*	*9*	*11*	*3*	*3*	*1*	..	..	..	..	..	*53*
			..	..	..	..	..	..	1	3	1	4	6	2	2	..	..	..	..	..	19
1006	322	,,	..	..	*2*	*2*	..	*5*	*2*	*8*	*16*	*9*	*4*	*3*	..	..	..	..	..	..	*51*
			..	..	..	..	..	2	1	1	4	4	2	4	1	..	..	..	..	..	19

5. *Seed colour*

The frequencies in F_2 indicated that brown markings such as occur in Type 80 were dominant to the Type 5 phenotype and that inheritance was on a monohybrid basis. The behaviour of cultures in F_3 is shown below :—

TABLE XIX

F behaviour of the inheritance of seed colour

No. of F_3 cultures and nature of parents in F_2	Segregation	Frequencies	
		Observed	Expected
46 cultures from plants belonging to F_1 and Type 80 phenotypes.	Pure	16	15·3
	Segregating 3 brown : one Type 5.	30	30·7
14 from plants with Type 5 seed.	Pure	14	14

The theory based on F_2 is confirmed.

In segregating cultures in F_3 we obtain a total ratio as shown below :—

——	Seed like F_1 and Type 80	Seed Type 5	Total
Observed	1514	494	2008
Expected (3 : 1)	1506	502	
Deviation	8·0		

S. E. = 19·40.

$\frac{\text{Dev.}}{\text{S. E.}} = \frac{8 \cdot 0}{19 \cdot 40} = 0 \cdot 41$. The fit is good.

It has already been stated in the consideration of F_2 that it is very probable that the inheritance of seed colour is on a more complicated basis than a monohybrid ratio. The reason for this is that the attempt to separate the F_1 and Type 80 phenotypes in F_2 gave the following segregations in F_3.

TABLE XX

F_3 behaviour of the inheritance of seed colour

No. of F_3 cultures and nature of their parents in F_2	Segregation	Frequencies	
		Observed	Expected on dihybrid basis
36 F_1	Pure F_1	2	4
	3 F_1 : 1 Type 80	4	8
	3 F_1 : 1 Type 5	10	8
	9 F_1 : 3 Type 80 : 4 Type 5	20	16
10 Type 80	Pure Type 80	2	3·3
	3 F_1 : 1 Type 80	8	*Nil*
	3 Type 80 : 1 Type 5	*Nil*	6·7
14 Type 5	Pure Type 5	14	14

The segregations of cultures in F_3 from the F_1 phenotype are suggestive but the behaviour of cultures from the Type 80 phenotype shows clearly that we are unable to distinguish with certainty between F_1 seed and Type 80 seed.

The behaviour of cultures in F_3 as regards seed colour is also shown in Table XII. It will be seen that every culture which was pure for "coloured" flower was pure for brown markings on seed and that every culture which was pure for "non-coloured" flower was also pure for Type 5 phenotype seed. The evidence of the "cross-overs" also supports the idea that linkage is absolute, for in every case of an F_3 culture from a cross-over parent in F_2 it was found that a segregation was taking place which should not have existed. Thus a plant diagnosed in F_2 as having Type 5 flower and coloured seed gave in F a segregation for flower colour into three F_1 : one Type 5 phenotypes and seed colour was also segregating. As already explained the development of red in the flower is very much affected by the season, amount of sunlight, etc., and the development of colour in the seed varies somewhat with the degree of ripeness, dryness, etc. The very few supposed cross-overs we, therefore, attribute to mistaken diagnosis in F_2 and consider that a single factor is responsible for red colour in the flower and brown markings on the seed.

Part II

THE INHERITANCE OF WILT-RESISTANCE

The mode of inheritance of flower colour, inflorescence, habit, stature and seed colour has already been described and shown to follow normal Mendelian ratios. If an F_2 population is grown in an infected field then the frequency of any particular morphological phenotype will depend not only upon the Mendelian probability of occurrence of this phenotype but also upon its chances of surviving the attack of the disease. If resistance to disease is a Mendelian character and if the factor or factors for resistance are linked with any factors for morphological characters then the phenotypic frequencies in an F_2 population in an infected field will be affected by differential rates of mortality. If, however, no such linkage exists then the phenotypic frequencies in the F_2 in an infected field will not be disturbed by disease and it is possible that the proportion of survivors may indicate the nature of the Mendelian ratio involved in the inheritance of disease-resistance.

F_1 GENERATION

F_1 was grown in artificially infected fields in 1928-29 and in 1932-33. The following table shows the percentage loss due to wilt in F_1 and in the parents in these fields.

TABLE XXI

Percentage loss due to wilt in F_1 and parents

Culture	Percentage loss		
	1928-29	1932-33	
	Barah plot 7	Barah plot 7	Lawn plot 2
Type 80 parent	7·3	18·6	2·2
Type 5 parent	98·7	97·3	95·5
F_1	8·3	26·5	27·9

Barah 7 had been infected for two seasons previous to 1928-29. It was used also in 1929-30 but was not infected again until 1932-33. Lawn plot 2 was infected for the first time in 1932-33. The figures show that the resistance of F_1 is much greater than that of the susceptible parent but less than that of the resistant parent. In 1928-29 the number of F_1 plants was only twelve and specially good seeds were selected for growing this population. It is possible, therefore, that a higher degree of resistance was shown by this population than is really characteristic of F_1. In 1932-33, however, the F_1 in Barah 7 consisted of 177 plants and that in Lawn plot 2 of ninety-three plants, populations large enough to give significant figures.

F_2 GENERATION

The F_2 generation was grown in 1929-30, 1932-33 and 1933-34. In the first case the F_2 was from F_1 plants which had survived in an infected field (Barah plot 7 in 1928-29); in the other two cases the F_1 plants from which the F_2 populations were raised had not been grown in infected fields.

TABLE XXII

Percentage loss due to wilt in F_2 and parents

Culture	Percentage loss			
	1929-30	1932-33		1933-34
	Barah plot 8	Barah plot 7	Lawn plot 2	Lawn plot 3
Type 80 parent . . .	47·5	18·6	2·2	14·0
Type 5 parent . . .	99·0	97·3	95·5	91·3
F_2 (Type 80 × Type 5) .	80·5	32·7	40·1	..
F_2 (Type 5 × Type 80) .	..	41·6	43·6	50·0

The loss in F_2 in Barah 8 was about eighty per cent but this field was very heavily infected having been in the experiment and under *rahar* for four successive seasons and as has been explained in a previous paper [McRae and Shaw, 1933], a resistant type even will lose its resistance under these conditions; in fact, we note that Type 80, the resistant parent, under these circumstances had a loss of forty seven per cent. In 1932-33 the F_2 was grown in fields which had not been infected with wilt for so long and, as a matter of fact, in Lawn plot 2 the infection had been given only in that season, and the plot had never before been under *rahar*. The loss due to wilt in F_2 in Lawn plot 2 was from 40 to 44 per cent, in Barah 7 from 33 to 42 per cent and in Lawn plot 3 about 50 per cent. The actual figures are shown in Table XXIII given below :—

TABLE XXIII

Loss due to wilt in six F_2 populations of rahar *cross Type 80 × Type 5 and reciprocal*

Culture	1929-30		1932-33		1933-34			
	Barah plot 8		Barah plot 7		Lawn plot 3		Lawn plot 2	
	No. of wilted plants	No. of survivors	No. of wilted plants	No. of survivors	No. of wilted plants	No. of survivors	No. of wilted plants	No. of survivors
F_2 (Type 80 × Type 5).	385	93	93	191	106	158	...	...
F_2 (Type 5 × Type 80).	...	...	72	101	92	119	516	508

In fields which have been artificially infected and which have not been continuously under *rahar* for successive seasons, the loss due to wilt in F_2 ranges from 32 to 50 per cent. A loss of 43 to 44 per cent was approximated to in three cases and gives the ratio of survivors to deaths of 9 : 7 or 27 : 37 ; these proportions suggest that two or three pairs of factors are concerned in the inheritance of resistance. But F_2 data are difficult to elucidate in this respect, since in spite of the care taken to secure uniform infection of a field, susceptible plants may escape and resistant plants may suffer from an uncontrolled and adverse physiological stimulus which renders them susceptible to infection. We may leave the consideration of this point for the moment and examine the phenotypic frequencies for flower colour and other characters in these F_2 populations which were grown in infected soil and sustained losses from wilt disease.

FLOWER COLOUR

When the F_2 is grown in a wilt-infected field the four flower colour phenotypes, which have already been described, occur almost in the normal 9 : 3 : 3 : 1 proportion. The phenotypic frequencies in the six F_2 populations studied under infected conditions are shown in Table XXIV :—

TABLE XXIV

Segregation in F_2 for flower colour in infected fields

Cross	Year	Plot	Observed frequencies				Expected frequencies on 9 : 3 : 3 : 1 ratio				Total No. of plants	χ^2	P
			F_1	T. 80	T. 5	Ringed	F_1	T. 80	T. 5	Ringed			
T. 80 × T. 5	1929-30	Barah 8	44	23	18	8	52·2	17·4	17·4	5·8	93	3·1793	Between 0·30 and 0·50
,,	1932-33	Barah 7	113	39	41	17	118·1	39·4	39·4	13·1	210	1·9351	,, 0·50 and 0·70
,,	,,	Lawn 2	79	47	27	10	91·7	30·6	30·6	10·2	163	11·0110	,, 0·02 and 0·01
T. 5 × T. 80	,,	Barah 7	53	25	25	10	63·6	21·2	21·2	7·1	113	4·0734	,, 0·20 and 0·30
,,	,,	Lawn 2	73	21	20	6	67·5	22·5	22·5	7·5	120	0·7869	,, 0·80 and 0·90
,,	1933-34	Lawn 3	270	97	83	38	274·5	91·5	91·5	30·5	488	3·0383	,, 0·30 and 0·50
		Total	632	252	214	89	667·6	222·6	222·6	74·2	1,187		

It is evidentthat the incidence of disease has not caused much distortion in the expected dihybrid ratio, except in Type 80 × Type 5 in Lawn plot 2, where an excess of Type 80 type of flowers has increased the value of the χ^2 enormously. This is possibly a case of wrong diagnosis in flower colour.

SEED COLOUR

Here again the phenotypes which have already been described occur in the infected fields in proportions which agree closely with expectations.

TABLE XXV

Segregation in F_2 for seed colour in infected fields

Cross	Year	Plot	Observed frequencies		Expected frequencies on 3 : 1 ratio		Total number of plants
			Seeds with brown markings like F_1 or T. 80	Seeds like T. 5	Seeds with brown markings like F_1 or T. 80	Seeds like T. 5	
T. 80 × T. 5	1929-30	Barah 8	61	23	63·0	21·0	84
"	1932-33	Barah 7	131	53	138·0	46·0	184
"	"	Lawn 2	139	43	136·5	45·5	182
T. 5 × T. 80	"	Barah 7	70	28	73·5	24·5	98
"	"	Lawn 2	61	21	61·5	20·5	82
"	1933-34	Lawn 3	355	114	351·75	117·25	469
Total	...	...	817	282	824·25	274·75	1,099

Deviation = 7·25.
S. E. = 13·91.
$\frac{\text{Dev.}}{\text{S. E.}} = \frac{7\cdot25}{13\cdot91} = 0\cdot52$. The fit is good.

INFLORESCENCE

The occurrence of the crowded and open phenotypes in F_2 populations under the incidence of disease is shown in Table XXVI which gives the phenotypic frequencies of survivors. Here again there is no indication of any selective action of the disease.

TABLE XXVI

Segregation in F_2 for type of inflorescence in infected fields

Cross	Year	Plot	Observed frequencies		Expected frequencies on 3 : 1 ratio		Total number of plants
			Crowded	Open	Crowded	Open	
T. 80 × T. 5 . .	1929-30 .	Barah 8 .	64	18	61·5	20·5	82
,, . .	1932-33 .	Barah 7 .	155	55	157·5	52·5	210
,, . .	,, .	Lawn 2 .	100	41	105·75	35·25	141
T. 5 × T. 80 . .	,, .	Barah 7 .	89	25	85·5	28·5	114
,, . .	,, .	Lawn 2 .	81	41	91·5	30·5	122
,, . .	1933-34 .	Lawn 3 .	380	140	390·0	130·0	520
Total .	...	...	869	320	891·75	297·25	1,189

Deviation = 22·75.
S. E. = 34·48.
$\frac{\text{Dev.}}{\text{S.E.}}=\frac{22\cdot75}{34\cdot48}=0\cdot66.$ The fit is good.

HABIT

The occurrence of the erect and spreading phenotypes among the survivors in F_2 under infected conditions also agrees with expectations as is shown in Table XXVII.

TABLE XXVII

Segregation in F_2 for plant habit in infected fields

Cross	Year	Plot	Observed frequencies		Expected frequencies on 3 : 1 ratio		Total number of plants
			Erects and Inters.	Spreaders	Erects and Inters.	Spreaders	
T. 80 × T. 5 . .	1929-30 .	Barah 8 .	71	12	62·25	20·75	83
,, . .	1932-33 .	Barah 7 .	151	59	157·50	52·50	210
,, . .	,, .	Lawn 2 .	111	37	111·00	37·00	148
T. 5 × T. 80 . .	,, .	Barah 7 .	91	23	85·50	28·50	114
,, . .	,, .	Lawn 2 .	82	39	90·75	30·25	121
,, . .	1933-34 .	Lawn 3 .	402	118	390·00	130·00	520
Total .	...	...	908	288	897	299	1,196

Deviation = 11.
S. E. = 14·54.
$\frac{\text{Dev.}}{\text{S. E.}}=\frac{11}{14\cdot54}=0\cdot76.$ The fit is good.

It is evident from the facts presented above that in the inheritance of flower colour, seed colour, type of inflorescence and habit, the normal phenotypic proportions among the survivors of an F_2 population under wilt disease were undisturbed and we may safely infer that the factors which are concerned with the inheritance of these characters are inherited independently of those which are concerned with the inheritance of wilt-resistance.

F_3 GENERATION

Since the phenotypic ratios for the characters studied in F_2 were not disturbed by the incidence of wilt disease in the F_2 population, we infer that the inheritance of wilt-resistance is not linked to that of these characters and that the genotypes which occur in F_2 under normal conditions also occur in the same proportions when the population is subjected to disease. With the object of further investigating this, two F_2 populations, which were grown in 1932-33, were carried to F_3 in an infected field in 1933-34. One of these F_2 populations was the complete progeny of a single F_1 plant, and was grown under normal uninfected conditions, it contained 193 individuals and will be referred to as the 'B' series. The other F_2 population was also the progeny of a single F_1 plant and was grown under infected conditions. In this population there were ninety-eight survivors, the seed of which was carried to F_3, this is referred to as the 'A' series.

Thus in the "B" series we should expect to obtain all possible genotypes in F_2 and in the "A" series we shall obtain in F_2 the genotypes which survive the incidence of wilt.

Table XXVIII shows the distribution of the loss due to wilt disease among the F_3 families of these populations and among the parent types (Types 5 and 80) in the same fields. Types 5 and 80 behave with reference to disease resistance in accordance with what has been previously described, the two F_3 populations, however, each contain cultures which cover the whole range from susceptibility to complete resistance.

TABLE XXVIII

Frequency distribution of number of cultures for different degrees of wilt infection in rahar *cross Type 5 × Type 80—F_3 in an infected field*

Year and series	Plot	Seed	Number of cultures with different percentages of wilted plants											Total	Remarks
			Up to per cent												
			0	10	20	30	40	50	60	70	80	90	100		
1933-34 A Series	Lawn 2 and part of Lawn 1	Type 5 .	...	...	...	...	...	...	...	...	...	...	9	9*	* Distribution of 9 rows of this type in A series and of 24 rows in B series. † Distribution of 12 rows of this type of A series and of 2 rows in B series. ‡ Distribution of different F_3 families, each family in one row.
		Type 80 .	7	3	1	1	...	...	...	...	...	...	...	12†	
		T. 5 × T. 80-F_3.	2	2	8	13	9	9	18	15	14	7	1	98‡	
1933-34 B Series.	Lawn 1	Type 5 .	...	...	...	...	...	1	2	2	1	1	17	24*	
		Type 80 .	2	...	...	...	...	...	...	...	...	...	...	2†	
		T. 5 × T. 80-F_3.	1	11	20	23	18	30	16	18	10	10	36	193‡	

Each culture occupied one row in the field and contained thirty to forty plants. In Series A, therefore, there were nine rows of Type 5 with 100 per cent loss and eight F_3 cultures with 20 per cent loss.

In ninety-eight cultures in F_3 from the survivors of the F_3 which were grown under infection (the " A " series), there were two families which had no deaths due to wilt, and which may be classed as very resistant, fifteen families which sustained a loss of 70 per cent due to wilt and one family which was completely destroyed by this disease. In the 193 cultures in F_3 from the complete F_2 which was grown under non-infected conditions (the " B " series), one family had no deaths, eighteen families had a loss of 70 per cent and thirty-six families were almost completely destroyed by wilt. These frequencies suggest that in the A-series most of the susceptible plants had been destroyed by disease in F_2 ; these susceptible plants were probably individuals which were either heterozygous for factors for resistance or homozygous for their complete absence, in fact they were the non-resistant genotypes. In the A-series about one per cent of the total number of families have a death rate of over ninety per cent but in the B-series, in which the elimination of the more susceptible genotypes in F_2 had not taken place, about eighteen per cent of the total number of cultures have a death rate of over ninety per cent. It follows that in the F_2 grown under infected conditions (A-series), the completely susceptible genotypes were destroyed and the resulting F_3 population is from almost entirely resistant and partially resistant genotypes. In both series the distribution of resistance and susceptibility among the F_3 families shows that the inheritance of wilt-resistance is dependent upon multiple factors.

It has already been shown from the inheritance of morphological characters in F_2 and F_3 that there is no linkage between the heritable factors for wilt-resistance and those for the morphological characters studied. From our knowledge of the genotypes which are phenotypically represented in F_3, it is possible to see how the loss due to wilt disease is distributed among the different genotypes. Thus for instance, if, in F_3, cultures which were " pure open " for the inflorescence character, appear uniformly to maintain a very low loss due to wilt, we should infer that this morphological phenotype was correlated or linked with disease resistance. If, however, in families which are pure for this morphological phenotype, and in other families in F_3 pure for some other character (*e.g.*, " pure F_1 flower "), all grades of resistance occur, we obtain further proof of the absence of linkage and the dependence of resistance upon multiple factors. This, as a matter of fact, is the case and is shown clearly in Tables XXIX to XXXII.

TABLE XXIX

The distribution of loss due to wilt among F_3 families in relation to the inheritance of the type of inflorescence

Phenotypes	F_3 Series	No. of cultures and percentages of wilted plants in each culture											No. of families	Remarks
		Up to per cent												
		0	10	20	30	40	50	60	70	80	90	100		
Pure open	A	...	...	2	3	4	2	6	2	2	1	...	22	Families with very small populations in Series B have not been considered in this comparison.
	B	1	3	3	7	2	8	4	6	1	...	4	39	
Pure crowded	A	2	...	1	2	1	2	5	2	5	1	...	21	
	B	...	4	4	4	3	6	1	1	2	2	1	28	
Segregating (3 crowded : 1 open).	A	...	2	5	8	4	5	7	11	7	5	...	54	
	B	...	3	13	12	13	15	11	11	7	9	8	102	

It is evident from Table XXIX that all grades of resistance occur in all genotypes both in " A " and " B " series.

TABLE XXX

The distribution of loss due to wilt among F_3 families in relation to the inheritance of flower colour

Phenotypes	F_3 Series	No. of cultures and percentages of wilted plants in each culture											No. of families	Remarks
		Up to per cent												
		0	10	20	30	40	50	60	70	80	90	100		
Pure F_1	A	...	...	1	...	...	...	1	...	...	1	...	3	Families with very small population in Series B have not been considered in this comparison.
	B	...	1	...	4	1	...	1	1	1	...	...	9	
3 F_1 : 1 T. 80	A	...	...	...	...	...	2	1	3	3	1	...	10	
	B	...	...	6	4	...	3	1	3	1	2	2	22	
3 F_1 : 1 T. 5	A	...	...	...	3	1	...	2	1	...	...	...	7	
	B	...	1	1	1	1	...	1	1	...	3	3	12	
9 F_1 : 3 T. 80 : 3 T. 5 : 1 Ringed.	A	2	2	3	3	4	2	4	5	3	...	...	28	
	B	...	3	7	7	5	11	6	2	4	3	2	50	
T. 80 Pure	A	...	...	1	...	...	...	1	2	1	1	...	6	
	B	...	...	2	2	3	4	1	1	...	1	...	14	
3 T. 80 : 1 Ringed	A	...	...	3	3	1	2	4	1	1	1	...	16	
	B	1	3	...	1	4	3	2	1	1	1	...	17	
T. 5 Pure	A	...	...	...	2	...	...	...	...	2	2	...	6	
	B	...	1	...	...	1	...	1	2	...	...	1	6	
3 T. 5 : 1 Ringed	A	...	...	...	2	3	2	3	3	...	1	...	14	
	B	...	...	3	2	2	4	2	6	3	...	...	22	
Ringed Pure	A	...	...	...	...	...	1	2	...	4	...	1	8	
	B	...	1	1	2	1	4	1	1	...	...	...	11	

TABLE XXXI

The distribution of loss due to wilt among the F_3 families in relation to the inheritance of seed colour

Phenotypes	F_3 families	No. of cultures and percentages of wilted plants in each culture											No. of families	Remarks
		Up to per cent												
		0	10	20	30	40	50	60	70	80	90	100		
Seeds with brown markings—Pure.	A	...	...	2	...	...	2	3	5	3	3	...	18	Families with very small populations in Series B have not been considered in this comparison.
	B	...	1	8	12	3	6	5	5	2	2	1	45	
Seeds with 3 brown markings: 1 silver-white segregating.	A	2	2	6	9	6	4	10	7	5	1	...	52	
	B	1	7	8	7	11	14	7	4	6	4	1	70	
Seeds silver-white—Pure.	A	...	...	...	4	3	3	5	3	6	3	1	28	
	B	...	2	4	4	4	8	5	7	2	...	3	39	

TABLE XXXII

The distribution of loss due to wilt among F_3 families in relation to the inheritance of plant habit

Phenotypes	F_3 families	No. of cultures and percentages of wilted plants in each culture											No. of families	Remarks.
		Up to per cent												
		0	10	20	30	40	50	60	70	80	90	100		
Erect—Pure .	A	...	...	1	3	1	...	2	2	3	...	1	13	Families with very small populations in Series B have not been considerred in this comparison.
	B	...	1	1	3	1	4	1	...	2	4	2	19	
Segregating 3 Erects and Inters : 1 Spreader.	A	2	1	6	2	5	6	12	12	6	4	...	56	
	B	1	7	13	13	13	21	11	11	7	7	7	111	
Spreader—Pure .	A	...	1	1	8	3	3	4	1	5	3	...	29	
	B	...	1	6	6	4	4	4	7	1	...	1	34	

Considering Tables XXIX to XXXII it is evident that the distribution of resistance to wilt disease among F_3 families is not dependent upon the genotypes for morphological phenotypes, which occur in these families. Taking for instance, the inflorescence character (Table XXIX) we notice that in both the A and B series all kinds of F_3 families, pure dominants, recessives and heterozygotes, show all grades of susceptibility. Considering Table XXVIII we note that in the B series a far larger total number of families in F_3 were completely destroyed by wilt, or destroyed to such an extent that no genetical deductions could be based on the few survivors, than in the A-series; these families of the B-series appear in Table XXVIII but they cannot appear in Tables XXIX to XXXII because it was impossible, owing to the small population or to the complete elimination of plants, to assign to them a probable genetical position in these tables. The total number of cultures shown for the B-series in Table XXIX is 169 whereas in Table XXVIII the B-series contains 193 cultures. All that can be certain is that the frequencies in the columns for 70 to 100 per cent loss due to wilt in the B-series in Tables XXIX to XXXII would be increased if these twenty-four cultures could be included in these Tables (Tables XXIX—XXXII).

Further proof of the correctness of the views based on the two F_3 populations described above is furnished by the subsequent generations derived from the first F_2 population of 1929-30 (Table XXXIII). In this cross there were ninety-three survivors in F_2, of which fifty-two had vigorous seed production and were selected as parents of F_3 cultures. The loss due to wilt disease was distributed among these fifty-two F_3 cultures as follows :—

TABLE XXXIII

Number of cultures from F_2, 1929-30 with different percentages of wilted plants in Barah plot 6

Culture	Percentage deaths						
	Up to per cent						
	0	10	20	30	40	—	80
F_3 (1930-31)	20	11	15	5	1		

Type 5 parent	74·3 per cent loss.
Type 80 parent	0·9 per cent loss.

It will be apparent that in this F_3, twenty families were completely resistant and that no family had a loss exceeding forty per cent. This is very interesting as it will be remembered that the F_2 of this cross was grown in a very heavily infected field and sustained a loss of about eighty per cent; that is to say, in F_2 practically all susceptible and partially susceptible genotypes were eliminated—hence this cross shows a much higher degree of resistance in F_3 than those previously described.

The distribution of loss due to wilt among these fifty-two F_3 families in relation to morphological characters is shown in Table XXXIV from which it will be apparent, as in the previous cases, that the distribution of loss was not correlated with any morphological character.

TABLE XXXIV

Distribution of loss due to wilt among F_3 families (1930-31) in relation to the inheritance of other characters

(Nature of segregations in F_3 families)

Percentage of wilted plants	Plant habit			Inflorescence			Flower colour							Seed colour					
	Erect	Spreader	Segregating Erect and Inters : Spreader	Crowded	Open	Crowded : Open	F_1	T. 80	T. 5	Ringed	F_1 : T. 80	F_1 : T. 5	F_1 : T. 80 : T. 5 : Ringed	T. 80 : Ringed	T. 5 : Ringed	Brown markings	Silver-white	Brown silver-white	No. of F_3 families in each grade of resistance
0 . .	1	8	11	5	3	12	2	1	2	2	4	2	1	2	4	8	8	4	20
Upto 5 per cent	...	1	4	1	2	2	1	...	...	...	...	...	2	1	1	1	1	3	5
,, 10 ,, .	1	1	4	...	1	5		1	...	1	...	2	1	1	...	1	1	4	6
,, 20 ,, .	1	...	14	2	3	10	...	3	...	1	3	2	3	2	1	7	2	6	15
,, 30 ,, .	...	1	4	1	...	4	...	...	...	...	...	2	2	...	1	...	1	4	5
,, 40 ,, .	...	...	1	...	...	1	...	...	1	...	...	...	...	...	...	...	1	...	1
Total .	3	11	38	9	9	34	3	5	3	4	7	8	9	6	7	17	14	21	52

Selected families from this particular cross have been carried up to the F_6 generation, some details of which are given below.

Four F_3 families were selected from this cross of 1929-30 for further study and the F_4 generation was grown in the same plot as the F_3, *viz.*, Barah 6 in 1931-32.

F_4 GENERATION

Selection in F_3 was made so as to secure various combinations of different morphological characters with wilt-resistance. Special stress was, however, given to selecting plants with erect habit, because *rahar* varieties with such habit are preferred on account of the ease in inter-cultivation, harvesting and threshing. Families B-69, D-22, E-4 and F-60 were selected for the purpose and their F_2 and F_3 characters are tabulated below :—

Table XXXV

F_2 and F_3 behaviour of selected families

Family	Percentage of wilted plants in F_3	Plant habit		Inflorescence		Flower colour		Seed colour	
		F_2	F_3	F_2	F_3	F_2	F_3	F_2	F_3
B-69	0	Spreader	Spreader	Open	Open	Ringed	Ringed	Silver-white like T. 5	Silver-white like T. 5
D-22	8	Erect	Erect	Crowded	Crowded : Open	T. 80	T. 80	Brown like F_1	Brown like F_1
E-4	16	Erect	Erect	Crowded	Crowded : open	T. 5	T. 5 : Ringed	Silver-white like T. 5	Silver-white like T. 5
F-60	0	Erect	Erect	Open	Open	F_1	F_1 : T. 80	Brown like T. 80	Brown like T. 80

It will be seen from the above table that family B-69 had no deaths due to wilt and was genetically pure for all the morphological characters studied. The remaining three families, on the other hand, each segregated for some particular morphological character or the other. Thus D-22 segregated for inflorescence while E-4 segregated for inflorescence and flower colour. A number of plants were selected from each of these segregating families as well as from B-69, which was pure for all characters, and these were carried on to F_4 generation.

E-4 was pure in F_3 for erect habit and silver-white seed colour like Type 5, but segregated for type of inflorescence and flower colour. The following table shows the characters of the palnts as regards inflorescence and flower colour selected in this family as parents for F_4.

TABLE XXXVI

Characters of plants selected in F_3

Nature of inflorescence	Flower colour		Total number of plants
	Typ⸗ 5	Ringed	
Crowded	3, 5, 6, 18, 25	11, 14, 16	8
Open	4, 8, 13	19	4
Total .	8	4	12

Figures in columns 2 and 3 in Table XXXVI denote plant numbers in F_3 families.

It will be apparent that five plants with crowded inflorescence and Type 5 flowers were selected, three with crowded inflorescence and ringed flowers, three with open inflorescence and Type 5 flowers and one plant with open inflorescence and ringed flowers.

F-60 was pure for erect habit, open type of inflorescence and brown seeds like Type 80, but segregated for flower colour. In this family twelve plants with F_1 flower colour and twelve plants with Type 80 flower were selected. The numbers of these plants being :—

F_1 flower colour . .	Plant Nos. 3, 4, 7, 8, 10, 11, 12, 13, 14, 16, 18 and 24.
Type 80 flower colour .	Plant Nos. 1, 2, 5, 9, 15, 17, 19, 20, 21, 22, 23 and 25.

D-22 was pure for erect habit, flower colour like Type 80 and brown seeds like F_1 but segregated for crowded and open types of inflorescence. Ten plants were selected in this family as follows :—

Crowded inflorescence .	Plant Nos. 3, 6, 11, 17, 18 and 23.
Open inflorescence .	Plant Nos. 5, 15, 16 and 19.

B-69 was pure for all morphological characters studied and hence only seven plants were selected from this family.

That multiple factors are responsible for the inheritance of wilt-resistance is further shown by the distribution of these fifty-three cultures in F_4 with reference to the loss due to wilt :—

TABLE XXXVII

Distribution of F_4 families according to deaths due to wilt

Family	Percentage of wilted plants in F_3 cultures	Frequency of families with different percentages of wilt in F_4								Total number of families
		Upto per cent								
		0	10	20	30	40	50	—	100	
F-60 . . .	0	9	10	4	1	..	..	—	..	24
D-22 . . .	8	5	..	1	1	1	1	—	1	10
E-4 . . .	16	1	1	5	3	1	1	—	..	12
B-69 . . .	0	5	2	..	..	..	..	—	..	7

Type 80 parent . . . . 0 per cent
Type 5 parent . . . . 79·8 per cent

It will be seen that families F-60 and B-69 which showed no deaths due to wilt in the F_3 had many cultures in F_4 with either no deaths or with not more than ten per cent of deaths. Nine families in F-60 showed no deaths while fifteen families had deaths ranging from ten to thirty per cent. In the case of families D-22 and E-4 which had eight per cent and sixteen per cent deaths in F_3 respectively, the range of distribution was much wider as is shown in the above table.

The distribution of F_4 families for the different morphological characters studied in relation to the percentage of wilted plants in each family is tabulated below :—

TABLE XXXVIII

Distribution of loss due to wilt among F_4 families (1931-32) in relation to the inheritance of other characters

Family	Percentage of wilted plants	Plant habit			Inflorescence			Flower colour									Seed colour			No. of families in each series
		Erect	Spreader	Erect : Spreader	Crowded	Open	Crowded : Open	F_1	T. 80	T. 5	Ringed	F_1 : T. 80	F_1 : T. 5	F_1 : T. 80 : T. 5 Ringed	T. 80 : Ringed	T. 5 : Ringed	Brown marking	Silver-white	Brown : silver-white	
F-60 . .	0	9	...	...	...	9	...	2	4	...	...	2	1	...	...	...	9	...	...	
	5	6	...	...	...	6	...	...	3	...	...	3	...	...	...	...	6	...	...	6
	10	4	...	...	...	4	...	1	1	...	...	2	...	...	...	...	4	...	...	4
	20	4	...	...	...	4	...	...	2	...	1	1	...	...	...	...	4	...	...	4
	30	1	...	...	...	1	...	...	1	...	...	...	...	...	...	...	1	...	...	1
E-4 . .	0	1	...	...	1	...	...	...	...	...	1	...	...	...	...	...	...	1	...	1
	5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	10	1	...	...	1	...	...	...	...	...	1	...	...	...	...	...	...	1	...	1
	20	5	...	...	2	2	1	...	...	2	3	...	...	...	...	...	...	5	...	5
	30	3	...	...	1	...	2	...	...	2	...	...	...	...	...	1	...	3	...	3
	40	1	...	...	...	1	...	...	...	1	...	...	...	...	...	...	...	1	...	1
	50	1	...	...	...	1	...	...	...	...	...	...	...	...	...	1	...	1	...	1
D-22 . .	0	5	...	...	3	2	...	...	5	...	...	...	...	...	...	...	5	...	...	5
	5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	10	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	1
	20	1	...	...	...	...	...	...	1	...	...	...	...	...	...	...	1	1	...	1
	30	1	...	...	...	1	...	...	1	...	...	...	...	...	...	...	1	...	...	1
	40	1	...	...	...	1	...	...	1	...	...	...	...	...	...	...	1	...	...	1
	50	1	...	...	...	...	1	...	1	...	...	...	...	...	...	...	1	...	...	1
	100	1	...	...	1	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...
B-69 . .	0	...	5	...	...	5	...	...	...	...	5	...	...	...	...	...	...	5	...	5
	5	...	2	...	...	2	...	...	...	...	2	...	...	...	...	...	...	2	...	2

F_5 GENERATION

A notable feature in the study of the F_5 generation was that not only the promising wilt-resistant hybrids descended from the families B-69, D-22, E-4, and F-60 were carried to F_5 but that five other families (A', B', C', D', E') of the same cross which were similar in morphological characters to the above but in which the previous generations had never been grown in fields artificially infected with wilt (the B-series– see page 172), were also included in order to determine their response to wilt.

The following cultures were selected for growing in F_5 :—

Table XXXIX

Description of selected cultures for F_5

Family	Cultures	Characters			Seed colour	Morphologically similar parents selected from F_4 in the B-series
		Plant habit	Inflorescence	Flower colour		
B-69	A.5	Spreading	Open	Ringed	T.5	A'.240
E-4	B.14	Erect	Crowded	Ringed	T.5	B'.620
E-4	C.15	Erect	Open	T.5	T.5	C'.1055
D-22	D-24	Erect	Crowded	T.80	F_1 Brown	D'.514
D-22	D-30	Erect	Crowded	T.80	F_1 Brown	..
D-22	D-32	Erect	Crowded	T.80	F_1 Brown	..
F-60	E-50	Erect	Open	T.80	T.80 Brown.	E'.562
F-60	E-39	Erect	Open	T.80	T.80 Brown.	—
F-60	E-57	Erect	Open	T.80	T.80 Brown.	—

The F_5 series A', B', C' D', E' had, therefore, been bred without any selection for resistance to wilt and were respectively morphologically similar to the F_5 cultures A-5, B-14, C-15, D-24, 30, 32, E-39, 57, 59 which had been bred for wilt-resistance. Table XXXIX makes clear the position of these F_5 cultures.

Cultures 28 and 38 derived from wilt-resistant families, D-51 and C-14 (from A series) respectively were also grown. Their morphological characters are shown below :—

TABLE XL

Description of two other wilt-resistant cultures

Family	Cultures	Plant habit	Characters		
			Inflorescence	Flower colour	Seed colour
D-51 . .	28	Erect .	Open .	T.80 .	Brown like F_1
C-14 . .	38	Erect .	Open .	F_1 . . .	Brown like F_1 and A_2

About three to five cultures of each family in Tables XXXIX and XL were grown in F_5 ; the seed of a single plant being sown in one row. The average loss due to wilt, in the field in which this F_5 was grown, sustained by the original parents was 84·9 per cent for Type 5 and 0·82 per cent in the case of Type 80. This F_5 was grown in a field which had been artificially infected for the first time.

TABLE XLI

Nature of wilt-infection in F_5 families, 1932-33

Previous generations grown in a wilt-infected field					Previous generations grown in a non-infected field				
Culture	Row No.	No. of effective plants	Deaths due to wilt		Culture	Row No.	No. of effective plants	Deaths due to wilt	
			No. of plants	Percentage				No. of plants	Percentage
A.5 .	2	46	1	2·17	A'.240 .	3	45	2	4·44
	35	44	3	6·82		36	46	1	2·17
	69	47	3	6·38		38	42	0	0
						71	44	1	2·27
B.14 .	4	46	3	6·52	B'.620 .	5	46	4	8·70
	33	48	3	6·25		34	47	46	97·90
	39	45	0	0		41	44	0	0
	67	45	1	2·22		68	46	33	71·80
C.15 .	6	47	16	34·05	C'.1055	32	34	32	94·20
	31	38	38	100·00		43	46	45	97·90
	37	45	42	93·40		7	45	45	100·00
	65	43	18	41·90		66	48	43	89·60
	42	45	0	0					

TABLE XLI—(*contd.*)

Previous generations grown in a wilt—infected field					Previous generations grown in a non-infected field.				
Culture	Row No.	No. of effective plants	Deaths due to wilt		Culture	Row No.	No. of effective plants	Deaths due to wilt	
			No. of plants	Percentage				No. of plants	Percentage
D.24	8	45	3	6·67	D'.514	9	45	44	97·80
	28	45	3	6·67		29	46	45	97·90
	44	45	0	0		45	41	38	92·79
	63	42	0	0		64	41	38	92·79
D.30	12	48	0	0					
	26	47	1	2·13					
	47	47	0	0					
	61	47	1	2·13					
D.32	13	46	0	0					
	25	44	1	2·27					
	48	47	1	2·13					
E.50	16	46	0	0	E'.562	17	46	44	95·70
	21	45	0	0		22	41	37	90·30
	52	46	0	0		53	46	43	93·50
	56	47	0	0		57	46	38	82·60
E.39	18	45	0	0					
	19	46	0	0					
	54	47	1	2·13					
	55	46	0	0					
28	11	45	0	0	Type 80	77	43	0	0
	27	45	0	0		83	43	0	0
	46	44	0	0		88	40	0	0
	62	46	0	0		95	38	2	5·26
						101	42	0	0
38	14	44	0	0		107	44	0	0
	24	43	0	0		113	47	0	0
	49	44	0	0		115	47	1	2·13
	59	43	0	0		116	48	0	0
					Total		392	3	0·76
					Type 5	1	43	42	97·7
						10	46	46	100·0
						20	45	44	97·8
						30	46	46	100·0
						40	46	44	95·7
						50	46	46	100·0
						60	45	39	86·8
						70	42	35	83·4
						73	39	32	82·1
						79	34	31	91·1
						85	40	26	65·0
						91	42	37	88·2
						97	39	33	84·7
						103	40	36	90·0
						109	45	42	93·4
					Total		638	579	90·75

The above table reveals the following facts :—

(1) That the cultures in the A (5) series showed a range of 2·17 to 6·82 per cent of deaths due to wilt while those in the A' (240) series had deaths ranging from 0 to 4·44 per cent. Both these morphologically similar phenotypic series may, therefore, be considered as wilt-resistant. The morphological characters in this group were spreading, open, ringed, T.5 seed, of which only the first two belong to the resistant parent.

(2) That the cultures in the B (14) series had 0 to 6·52 per cent deaths while those in B' (620) series had a range of 0 to 97·90 per cent. This shows that the B series was nearly pure for wilt resistance but that the B' series was segregating for this character, although both B and B' were identical for the morphological characters studied. The morphological characters in this group were erect, crowded, ringed, T. 5 seed, most of these characters belong to the susceptible parent.

(3) That the cultures in the C (15) series exhibited a range of 0 to 100·0 per cent deaths due to wilt, and the hybrids in the parallel series C'(1055) a range of 89 per cent to 100 per cent deaths, suggesting that the series C contained some cultures which were resistant, some which were very susceptible and some which were partially susceptible and that the series C' was almost fully susceptible to wilt. Of the morphological characters in this group only one character, open inflorescence, belonged to the resistant parent.

(4) That the cultures in the D series were highly resistant to wilt is shown by D (24) having 0 to 6·67 per cent deaths, D (30) showing 0 to 2·13 per cent and D (32) showing a similar 0 to 2·27 per cent deaths due to wilt. The cultures in the corresponding series D' (514), on the othar hand, all showed a very high degree of susceptibility, *viz.*, 92·79 to 97·90 per cent, suggesting that the two series were absolutely dissimilar in their power of resistance to wilt disease although they were similar to one another in other morphological characters, two of which belonged to the susceptible parent.

(5) Similarly all the cultures in series E were highly resistant to the disease but their morphologically similar phenotypes in series E' (562) were very susceptible. All the cultures in E (50) had no deaths and one death only occurred in a culture in E 39 and one in a culture in E 57. The cultures in E' (562) had deaths ranging from 82·60 to 95·70 per cent. In this group all the characters except the erect habit belonged to the resistant parent.

Cultures 28 and 38 also sustained no loss due to wilt, they were pure for the erect character of the susceptible parent.

The foregoing details again confirm our previous observations that the wilt-resistant property in this *rahar* cross segregates quite independently of all the morphological characters studied. Had there been any correlation of morphological characters with resistance or susceptibility to wilt, similar phenotypes derived either from wilt-infected or non-infected fields would have responded similarly to wilt-infection.

Plate XXVI shows graphically the percentage of deaths due to wilt shown by the different F_5 cultures as well as by different rows of the two parents.

SUMMARY AND CONCLUSIONS

(1) The paper describes the inheritance of certain morphological characters and the inheritance of wilt-resistance in a cross between two unit species of *Cajanus indicus*. The types used in this cross were the Pusa Types T.5 and T.80.

(2) The inheritance of flower colour followed a 9 : 3 : 3: 1 ratio—the F_1 and the double recessive being new phenotypes unlike either parent.

(3) Erect habit was partially dominant to the spreading habit on a 3 : 1 ratio.

(4) Short stature was dominant to tall on a 3 : 1 ratio.

(5) The crowded habit of the inflorescence was dominant to the open on a 3 : 1 ratio.

(6) The brown seed of T. 80 was dominant to the silver-white of T. 5 on a 3 : 1 ratio although in this case we suspect a more complicated system of inheritance but the impossibility of diagnosing the F_1 phenotype correctly led to the adoption of the simple 3 : 1 theory.

(7) The F_2 and F_3 populations were grown in infected fields and the loss due to wilt in F_2 suggests that the inheritance of resistance may be found in a 9 : 7 or 27 : 37 ratio, resistance being dominant.

(8) The ratios of the various phenotypes in F_2 were not disturbed by the incidence of the disease showing that the inheritance of resistance was not linked with that of any of the morphological characters studied.

(9) Phenotypes which possessed the quality of resistance to wilt disease and most of the morphological characters of the susceptible parent were isolated from the cross (Table XLI, Culture B·14, Row 39).

(10) Morphologically identical hybrids showed great variation in their behaviour to wilt disease, from almost complete resistance to complete susceptibility.

I have to thank Mr. R. D. Bose, officiating Assistant Economic Botanist, and Mr. Hukam Singh, Assistant, Botanical Section, for a large amount of assistance in the course of this investigation.

REFERENCES

Butler, F. J. (1910). *Mem. Dept. Agric. Ind., Bot. Ser.* **2**, No. 9.

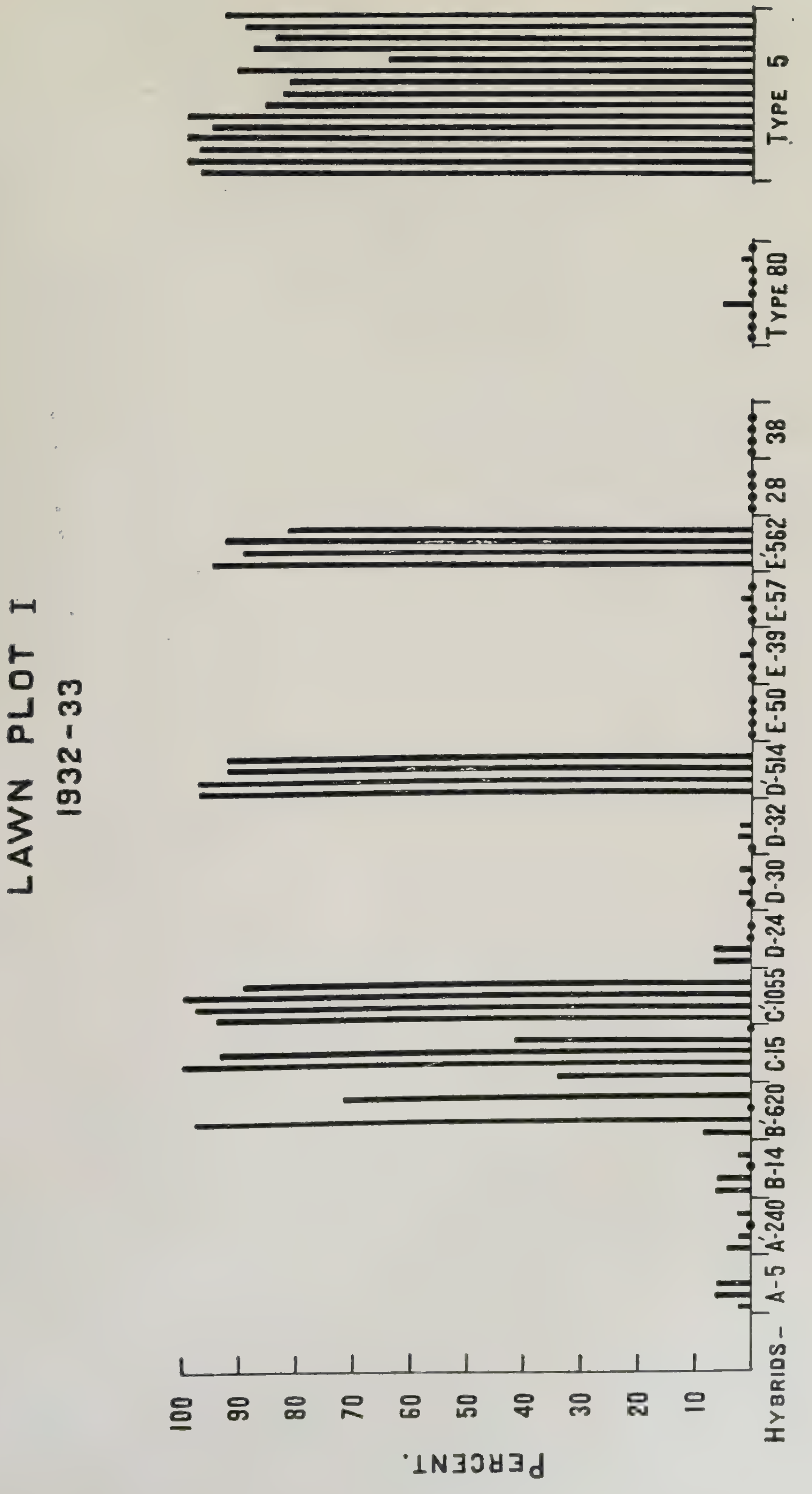
McRae, W., and Shaw, F. J. F. (1933). *Sci. Monograph of the Imp. Coun. of Agric. Res.* No. 7, 1—68.

McRostie, G. P. (1919). *Phytopath.* **9**, 141—148.

Norton, J. B. (1908). *Trans. Peninsula Hort. Soc.* 1908, 1-4.

Orton, W. A. (1908). *U. S. Dept. Agric. Yearbook*, 1908, 453-464.

———— (1911). *IV Inter. Conf. Genet.* 247-261.



Deaths due to Wilt in F_5 cultures of Pigeon-pea Cross Type 80× Type 5 and in the Parents

Shaw, F. J. F., Khan, A. R., and Singh, H. (1933). *Ind. J. Agric. Sci.* **3**, 1-36.

Spinks, G. T. (1913). *J. Agric. Sci.* **5**, 231-247.

Tisdale, W. H. (1917). *J. Agric. Res.* **11**, 573-605.

Wade, B. L. (1929). *Wisconsin Agric. Expt. Stn. Res. Bull.* **97**.

Woollenweber, H. W. (1913). *Phytopath.* **3**, 24-48.

Sci. Rep. of the Imp. Inst. of Agric. Res., Pusa, 1928-29, pp. 22-23 ; 1929-30, pp. 24-25 ; 1930-31, p. 35 ; 1931-32, p. 64 ; 1932-33, pp. 12-13.

STUDIES ON *SCHISTOCERCA GREGARIA* FORSK.*

II. THE BIOLOGY OF THE DESERT LOCUST WITH SPECIAL RELATION TO TEMPERATURE

BY

M. AFZAL HUSAIN, M.A., (CANTAB), I.A.S.,

AND

TASKHIR AHMAD, B.Sc. (AGRI.) (PUNJAB),

Locust Research Laboratory, The Punjab Agricultural College, Lyallpur

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CONTENTS

	PAGE
1. INTRODUCTION	189
2. PRE-COPULATION AND PRE-OVIPOSITION PERIOD	190
(*i*) Pre-oviposition period at constant temperatures	190
(*ii*) Pre-oviposition period at a temperature varying between 28° and 32°C	193
(*iii*) Pre-oviposition period of the over-wintered adults at laboratory temperature	193
(*iv*) Pre-oviposition period of the summer brood at laboratory temperature during April—July	195
3. INTER-OVIPOSITION PERIOD	196
(*i*) Inter-oviposition period of females kept at constant temperatures	196
(*ii*) Inter-oviposition period in adults kept in the hot house at a temperature varying between 28° and 32°C.	198
(*iii*) Inter-oviposition period at laboratory temperature during different months of the year	199
(*iv*) Winter intervening between two ovipositions	203

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*Studies on *Schistocerca gregaria* Forsk. I. The Micropyle in *Schistocerca gregaria* Forsk. and some other Acridiidae. *Ind. J. Agric. Sci.* **3**:639-645, 1933.

	PAGE
4. NUMBER OF OVIPOSITIONS BY A FEMALE	203
5. OVIPOSITION	204
(*i*) Oviposition at high soil temperature	204
(*ii*) Oviposition at low soil temperature	207
6. INCUBATION	209
(*i*) Incubation of eggs at constant temperatures	210
(*a*) Threshold of development	211
(*b*) Incubation period at constant temperatures	214
(*c*) Vital limits for the eggs	218
(*ii*) Incubation period at alternating temperatures	219
(*iii*) Incubation period under varying temperatures in breeding cages kept in the open	221
(*iv*) Incubation period at laboratory temperature during different months	223
7. DURATION OF LARVAL STAGES	226
(*i*) Duration of larval stages at constant temperatures	227
(*ii*) Upper vital limit	243
(*iii*) Duration of larval stages at laboratory temperature	245
(*iv*) Duration of larval stages in the case of hoppers caged on plants in the open, during winter	247
8. LONGEVITY OF THE WINGED STAGE	249
9. TOTAL LIFE AND NUMBER OF BROODS IN A YEAR	259
10. SUMMARY	261
REFERENCES	261

1. Introduction

It is now fully recognized that without a thorough study of the biology and, more particularly, the ecology of a pest it is not possible to evolve a scientific system of prevention and control. This is particularly true of such sporadic pests as the Desert Local. During a locust visitation all energies are directed towards the destruction of this scourge and when it is over everything is forgotten. Moreover, the Desert Locust lives permanently in more or less uninhabited tracts, and out of sight is out of mind. Appreciating the importance of a thorough study of the Desert Locust from every aspect, the Imperial Council of Agricultural Research in India initiated and financed, in 1930, a scheme for locust research on an all-India basis. A part of the programme of this scheme consisted in the study of the influence of environmental factors on the bionomics of the Desert Locust. The present paper deals with one aspect of this investigation, *viz.*, the influence of temperature—one of the most important factors in the environmental complex of the locust—on the various stages of this insect. Studies at constant temperatures have been supplemented by a large number of observations at room temperature, and even under natural environmental conditions.

The locusts employed in these experiments were obtained, both in the adult and hopper stages, from the swarms visiting the Punjab during the winter of 1930, and their progeny bred in the laboratory under different conditions. Later on collections of the 'solitary' phase adults were made from the permanent breeding grounds in Sind and South Baluchistan.

Unfortunately we started our investigations at the close of the last swarming cycle and have not been able to obtain sufficient material for as thorough an investigation as we desired. We have already greatly delayed the publication of these results in the expectation of another visitation. However, as there appears no immediate prospect of this, and, as we believe, that the results obtained would be useful to other workers, in India and elsewhere, we are publishing them.

Our thanks are due to the Imperial Council of Agricultural Research for providing funds.

2. Pre-copulation and Pre-oviposition period of *Schistocerca Gregaria*

The female locusts usually begin to oviposit almost immediately after copulation. In fact very frequently the female begins her digging operations and egg-laying while the male is still on her back. Therefore, for all intents and purposes, the pre-copulation and pre-oviposition periods (*i.e.*, the period between the last larval moult and the first coitus and first oviposition), are identical. Varying opinions have been expressed regarding the duration of this period in *Schistocerca gregaria*. Bodenheimer [1929] considers that for a normal development a full year is required, of which the pre-oviposition period is ten months. According to Regnier [1926] copulation takes place forty to fifty days after the last larval moult. Telenga [1930] states that the adults begin to pair a month after acquiring wings. Cotes [1891] and Vosselar [1905] observed the first oviposition two to three weeks after the last moult. Such widely differing statements may be accepted as correct, because evidently observations by the different investigators were made under different environmental conditions. Unfortunately no mention of these conditions has been made.

I. PRE-OVIPOSITION PERIOD AT CONSTANT TEMPERATURES

The results of observations on locusts bred at constant temperatures are given in Table I and Fig. 1.

TABLE I

Pre-oviposition period at constant temperatures (1931 & 1932)

Reference No.	Temperature to which adults exposed (°C.)	Date of acquiring wings	Date of first oviposition	Pre-oviposition period (days)
(Hoppers bred crowded at 40°C.; 1932)				
40/I A2	40	29th Jan.	11th Feb.	13
40/I A3	40	29th Jan.	11th Feb.	13
40/II A1	40	14th March	31st March	17
40/II A2	40	14th March	28th March	16
			Average	14·2
(Hoppers bred crowded at 36°C.; 1931)				
N_1	36	13th March	1st April	19
N_2	36	17th March	31st March	14
N_4	36	17th March	31st March	14
N_5	36	17th March	30th March	13
N_3	36	19th March	1st April	13
T_2	36	14th May	2nd June	19
T_3	36	17th May	5th June	19
III_3	36	13th July	3rd Aug.	21
III_2	36	14th July	4th Aug.	21
III_1	36	14th July	6th Aug.	23
			Average	17·6
(Full-grown hoppers collected from a swarm; 1931)				
30 A	30	10th Jan.	5th Feb.	26
29 C	30	10th Jan.	7th Feb.	28
29 A	30	10th Jan.	27th Jan.	17
30 B	30	10th Jan.	5th Feb.	26
			Average	24·2
(Hoppers bred crowded at room temperature; 1931)				
L 66	27	18th Jan.	19th Feb.	32

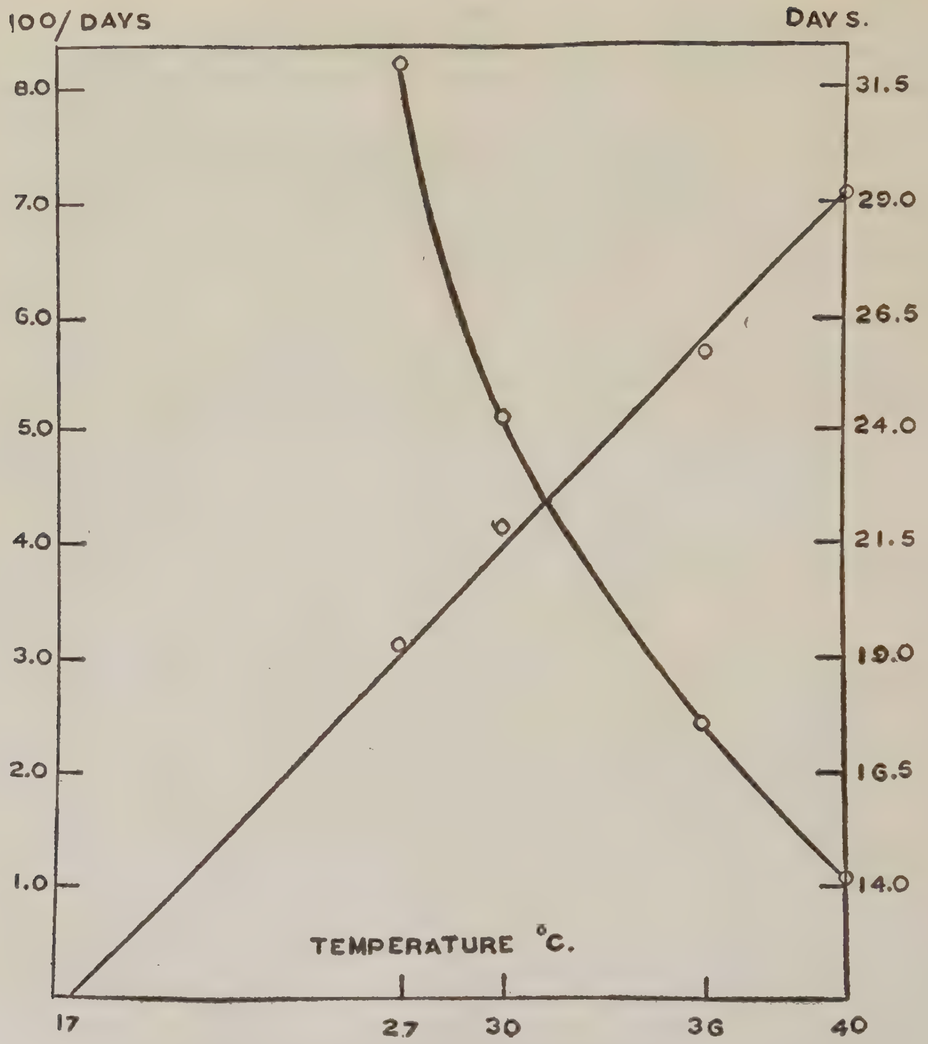

Fig. 1. Time-temperature and temperature-rate curves of pre-oviposition period of *Schistocerca gregaria* adults.

The influence of temperature on the pre-oviposition period is quite significant. The higher the temperature, within certain limits, the shorter the pre-copulation and pre-oviposition period. The shortest period recorded has been thirteen days at 36°C., and 40°C. At 27°C., however, it was thirty-two days. At one and the same constant temperature the period varies from individual to individual. At 40°C., it varied from thirteen to seventeen days, at 36°C., from thirteen to twenty-three days, at 30°C., from seventeen to twenty-eight days and at 27°C., it was thirty-two days.

II. PRE-OVIPOSITION PERIOD AT A TEMPERATURE VARYING BETWEEN 28°C. AND 32°C.

Some of the breeding cages were kept in an artificially heated hot house, the temperature of which was maintained between 28°C. and 32°C. Under these conditions the pre-oviposition period varied from fifteen to twenty-eight days (Table II). These results agree with those above stated.

TABLE II

Pre-oviposition period in the hot house

(Temperature varying from 28-32°C.)

Previous history: Hoppers of V stage were collected from a swarm during 1930 and bred in the laboratory; their progeny was used in these experiments.

(1931 & 1932)

Reference No.	Date of acquiring wings	Date of 1st oviposition	Pre-oviposition period (days)
L_1	24th Sept.	18th Oct.	24
L_6	24th Sept.	17th Oct.	23
L_9	24th Sept.	16th Oct.	22
L_{17}	24th Sept.	16th Oct.	22
L_{36}	24th Sept.	26th Oct.	32
L_{38}	26th Dec.	20th Jan.	25
L_{39}	3rd Jan.	18th Jan.	15
L_{49}	5th Jan.	26th Jan.	21
		Average .	24·2

III. PRE-OVIPOSITION PERIOD OF THE OVER-WINTERED ADULTS AT LABORATORY TEMPERATURE

The adults, bred in the laboratory, from hoppers collected from a swarm and which had acquired wings in October 1930, were kept in cages in a large laboratory, during the winter 1930-31. The earliest oviposition occurred in the beginning of February. The average duration of the pre-oviposition period was 131 days, and the longest pre-oviposition period was almost seven months. The temperature of this laboratory remained below 18°C. (the developmental zero) during December and January. Oviposition commenced in the beginning of the spring when the maximum temperature rose to about 21°C.. (Table III). If the temperature remains low over a longer period, it is not unlikely that the pre-oviposition period may be as long as ten months, as stated by Bodenheimer [1929]. These observations represent, to a very large extent, what happens under natural conditions. The individuals acquiring wings in the beginning of winter over-winter as adults.

TABLE III

Pre-oviposition period of the over-wintered brood at laboratory temperature

Previous history: V stage hoppers collected from a swarm.

Reference No.	Date of acquiring wings (1930)	Date of 1st oviposition (1931)	Pre-oviposition period (days)
39 A	16th Aug. to 6th Sept.	24th Feb.	171—192
39 B	Do.	17th March	192—213
47 A	2nd to 7th Oct.	23rd Feb.	139—144
47 B	Do.	27th Feb.	143—148
48 A	Do.	18th Feb.	134—139
41	16th Oct. to 3rd Nov.	26th Feb.	115—133
46 B	Do.	7th March	124—142
40 A	16th Oct. to 24th Nov.	15th March	111—150
40 B	Do.	19th Feb.	87—126
35	17th Oct.	30th Jan.	105
	18th Oct.	29th Jan.	103
13	Do.	10th Feb.	115
18 A	20th Oct.	27th Jan.	99
18 B	Do.	11th Feb.	111
49 A	27th to 31st Oct.	3rd March	123—127
50 B	Do.	19th March	139—143
51 B	Do.	15th March	135—139
53	Do.	22nd March	142—146
54	Do.	24th March	144—148
		Average	133

IV. PRE-OVIPOSITION PERIOD AT LABORATORY TEMPERATURE DURING APRIL-JULY

During April to July the temperature of the laboratory, which served as our main rearing room, varied from 28° to 32°C., and the range of the pre-oviposition period was sixteen to thirty-two days (Table IV). These observations confirm those in the hot house (see p. 193.).

TABLE IV

Pre-oviposition period at room temperature from April to July 1931 (Temp. 28-32 C.)

Previous history: Hoppers were bred in cages at room temperature.

Reference No.	Date of acquiring wings	Date of 1st oviposition	Pre-oviposition period (days)
N 7 b2	2nd April .	4th May .	32
N 11	5th to 9th April	9th May .	30—34
I 9	27th to 30th April.	26th May .	26—29
I 9	27th to 30th April.	28th May .	28—31
I 10	5th to 8th May	30th May .	22—25
I 12	5th to 10th May	30th May .	20—25
I 12	5th to 10th May	30th May .	20—25
I 7	5th to 10th May	28th May .	18—23
I 11	5th to 12th May	28th May .	16—23
I 11	5th to 12th May	29th May .	17—24
R 43 d	8th to 13th May	4th June .	22—27
I 14	26th to 29th June.	28th July .	29—32
Q 1	11th to 15th July.	7th August .	23—27
		Average .	25·4

The observations given above make it abundantly clear that in the adult stage of the Desert Locust there is no diapause, in the true sense; in other words the rythm of development is not fixed, but is directly dependent on temperature, and perhaps also on other environmental conditions. By exposing adults to a temperature of 36° to 40°C., the pre-copulation and pre-oviposition period was reduced to thirteen days or so, and by keeping insects at a lower temperature it was prolonged to 141 days and over.

There is abundant evidence that in nature, in the Punjab, there are two distinct broods of the Desert Locust. The audits which emerge during September to November, over-winter in this stage, and begin to copulate and oviposit from February onwards. In certain warmer parts of India these processes may start earlier. As stated above the earliest recorded date of oviposition for the Punjab is 7th February. In the case of this over-wintering brood the pre-oviposition period may be as long as seven months. The adults that develop from the progeny of these over-wintered adults acquire wings from April onward, and their pre-oviposition period is not very long as copulation and egg laying start in July. April to September are the months of high temperature and during October to February the temperature is low. Hence it is evident that it is mainly temperature that controls the pre-copulation and pre-oviposition period, or in other words, the sexual maturity of the adults.

It is also evident that there must be individual differences under the same conditions of temperature, since such factors as morphological and physiological individual variations, food supply, etc., must operate.

3. Inter-oviposition period

Schistocerca gregaria, as is well known, lays a number of egg-pods, at intervals. The interval between two successive ovipositions varies. Regnier [1926] observed that the females oviposited at intervals of fifteen to twenty days. From his field observations, Bodenheimer [1929] recorded two ovipositions by the same swarm: one at the end of February and the other in the beginning of April. Ballard and others [1932] give one day as the minimum, thirty-nine days as the maximum and five to seven days as the normal interval between two successive ovipositions.

I. INTER-OVIPOSITION PERIOD OF FEMALES KEPT AT CONSTANT TEMPERATURES (TABLE V)

The observations made at constant temperatures show that the minimum inter-oviposition period is three days at 40°, 36° and 30°C. The variation is three to seven days at 40°C. (average 4·8 days); three to seven days at 36°C. (average 4·6 days), and three to twenty-four days at 30°C. (average 9·3 days), and a single observation at 27°C gave the inter-oviposition period as twelve days.

TABLE V

Inter-oviposition period at constant temperatures

Previous history: Hoppers bred crowded in thermostats at the same temperature to which adults were exposed.

Reference No.	Temperature	Dates of oviposition					Inter-oviposition period (days)
		I	II	III	IV	V	
				(1932)			
40 I A2 . .	40°C. .	27th Feb.	5th March	10th March	...	...	7, 5
40 II A1 . .	Do. .	1st April	4th April	8th April	...	...	
40 II A1 . .	Do. .	8th April	13th April	...	...	...	3, 4
						Average .	4·8
				(1931 & 1932)			
N 6 . .	36°C. .	30th March	2nd April	5th April	...	...	3, 3
N 2 . .	Do. .	31st March	7th April	...	...	...	7
N 1 . .	Do. .	1st April	5th April	...	...	...	4
N 3 . .	Do. .	1st April	4th April	...	...	...	3
I 2 . .	Do. .	2nd June	7th June	...	...	...	5
III 2 . .	Do. .	4th Aug.	11th Aug.	...	...	...	7
A 1 . .	Do. .	18th Oct.	24th Oct.	...	...	...	6
N 2 . .	Do. .	18th Oct.	24th Oct.	...	...	...	6
L 61 . .	Do. .	5th Feb.	8th Feb.	12th Feb.	...	...	3, 4
2 . . .	Do. .	5th Feb.	9th Feb.	13th Feb.	...	...	4, 4
1 . . .	Do. .	7th Feb.	11th Feb.	16th Feb.	...	...	4, 5
3 . . .	Do. .	8th March	12th March	18th March	...	...	4, 6
						Average .	4·6
				(1932)			
29 B . .	30°C. .	23rd Jan.	27th Jan.	31st Jan.	6th Feb.	...	4, 4, 6
29 A . .	Do. .	27th Jan.	8th Feb.	23rd Feb.	...	...	12, 15
30 B . .	Do. .	5th Feb.	13th Feb.	23rd Feb.	6th March	16th March	8, 10, 12,10
30 A . .	Do. .	5th Feb.	10th Feb.	16th Feb.	5th March	...	5, 6, 18
29 C . .	Do. .	7th Feb.	19th Feb.	14th March	17th March	...	12, 24, 3
						Average .	9·8
				(1932)			
L 6 . .	27°C. .	19th Feb.	2nd March	...	...	...	12
						Average .	12

II. INTER-OVIPOSITION PERIOD OF ADULTS KEPT IN THE HOT HOUSE AT A TEMPERATURE VARYING BETWEEN 28 AND 32°C.

In the adults kept in the hot house, the temperature of which was maintained at 28 to 32°C., the inter-oviposition period varied from three to twenty-eight days, the average being 10·2 days (Table VI). It is interesting to note that this agrees fairly closely with the average for 30°C. constant.

TABLE VI

Inter-oviposition period in the hot house (Temperature 28-32°C.) (1931 & 1932)

Previous history: V stage hoppers collected from swarms and bred in the laboratory.

Reference No.	Dates of oviposition				Inter-oviposition period (days)
	1st	2nd	3rd	4th	
L 9 . .	16th Oct. .	2nd Nov. .	30th Nov.	16th Dec.	17, 28, 16
L 14 . .	12th Nov.	16th Nov.	24th Nov.	28th Nov.	4, 8, 4
L 21 . .	16th Nov.	8th Dec.	12th Dec.	. .	22, 10
L 8 . .	24th Nov.	1st Dec.	5th Dec. .	8th Dec. .	7, 4, 3
L 53 . .	4th Feb.	12th Feb.	16th Feb.	24th Feb.	8, 4, 8
				Average .	10·2

III. INTER-OVIPOSITION PERIOD AT LABORATORY TEMPERATURE DURING DIFFERENT MONTHS OF THE YEAR

In Table VII are given data concerning the oviposition of the females which were kept inside the laboratory, except during February and March when they were exposed to the sun for a few hours every day. It will be seen that from April to August, when the daily average temperature ranged from 30° to 34°C., the inter-oviposition period varied mostly from five to seven days, while in February and March when the temperature in the laboratory remained below 30°C., the inter-oviposition period varied from ten to thirty days in February and five to thirty-five days in March. Thus while the longest inter-oviposition period during April to August was only fourteen days, it was thirty-five days during February and March.

TABLE

Inter-oviposition period

Reference No.	Previous history	Dates of oviposition.					
		1st	2nd	3rd	4th	5th	6th
18 A	Fifth stage hoppers collected from a swarm and bred in the laboratory.	27th Jan.	18th Feb.	4th March	15th March	21st March	31st March
No. 8		29th Jan.	28th Feb.	4th April	13th April	...	...
35		30th Jan.	12th Feb.	26th Feb.	8th March	19th March	24th March
No. 13		10th Feb.	26th Feb.	11th March	29th March	...	...
18 B		11th Feb.	6th March	?	?	24th March	...
48 A		18th Feb.	12th March	24th March	29th March	...	...
40 B		19th Feb.	7th March	27th March	3rd April	17th April	...
47 A		23rd Feb.	14th March	24th March	1st April	6th April	10th April
39 A		24th Feb.	9th March	19th March	27th March	7th April	...
41		26th Feb.	9th March	19th March	29th March	12th April	...
47 B		27th Feb.	14th March	21st March	26th March	1st April	6th April
46 B		7th March	16th March	27th March	...	...	...
51 B		15th March	29th March	3rd April	...	...	...
40 A		15th March	3rd April	9th April	...	...	...
39 B		17th March	23rd March	28th March	3rd April	9th March	...
50 B		19th March	26th March	6th April	...	...	...
53		22nd March	27th March	4th April	...	...	...
54		24th March	31st March	4th April	...	...	...
I 9A	Hoppers bred crowded in the laboratory from the very beginning.	26th May	2nd June	...	...	...	...
I 7		28th May	5th June	...	...	...	...
I 11		29th May	5th June	...	...	...	...
I 12		30th May	3rd June	...	...	...	...
I 14		24th June	28th June	6th July	10th July	...	...
Q 14		11th July	19th July	...	...	...	...
Q 4		23rd July	28th July	...	...	...	...
I 11		3rd August	8th August	...	...	...	...
I 15		7th August	13th August	...	...	...	...

VII

at room temperature (1931)

				Inter-oviposition period								
7th	8th	9th	10th	1	2	3	4	5	6	7	8	9
6th April	...	...	...	22	14	11	6	10	6	...	...	...
...	...	...	...	30	35	9	...	...	...	...	...	...
28th March	3rd April	8th April	14th April	13	14	10	11	5	4	6	5	6
...	...	...	...	16	13	18	...	...	...	...	...	...
...	...	...	...	23	...	...	...	...	...	...	...	...
...	...	...	...	22	12	5	...	...	...	...	...	...
...	...	...	...	16	20	7	14	...	...	...	...	...
16th April	...	...	...	19	10	8	5	4	6	...	...	...
...	...	...	...	13	10	8	11	...	...	...	...	...
...	...	...	...	11	10	10	14	...	...	...	...	...
11th April	...	...	...	15	7	5	5	5	5	...	...	...
...	...	...	...	9	11	...	...	...	...	...	...	...
...	...	...	...	14	5	...	...	...	...	...	...	...
...	...	...	...	19	6	...	...	...	...	...	...	...
...	...	...	...	6	5	6	6	...	...	...	...	...
...	...	...	...	7	11	...	...	...	...	...	...	...
...	...	...	...	5	8	...	...	...	...	...	...	...
...	...	...	...	7	4	...	...	...	...	...	...	...
...	...	...	...	7	...	...	...	...	...	...	...	...
...	...	...	...	8	...	...	...	...	...	...	...	...
...	...	...	...	7	...	...	...	...	...	...	...	...
...	...	...	...	4	...	...	...	...	...	...	...	...
...	...	...	...	4	8	4	...	...	...	...	...	...
...	...	...	...	8	...	...	...	...	...	...	...	...
...	...	...	...	5	...	...	...	...	...	...	...	...
...	...	...	...	5	...	..	...	...	...	...	...	...
...	...	...	...	8	...	..	...	...	...	...	...	...

In Table VIII the data of Table VII have been summarised under separate months, and the conclusions mentioned above find full support. As temperature increases progressively from month to month the inter-oviposition period of the Desert Locust decreases. It may, however, be stated that in the Punjab, under natural conditions, eggs are very rarely laid during May and June, oviposition in the over-wintered brood starts in February and in the case of the spring brood, in July.

TABLE VIII

Inter-oviposition period (days) during different months (1931) at room temperature.

Month	Average room temperature (°C.)	Individual observations on inter-oviposition period	Average
February	12·2 to 14·5	30, 16, 22, 14, 23, 13, 14, 10, 13, 16, 11, 22.	17·0
March	19·3 to 22·0	35, 13, 18, 11, 6, 10, 11, 5, 4, 10, 8, 6, 5, 19, 20, 10, 10, 9, 19, 10, 15, 7, 5, 6, 12, 5, 7, 11, 14, 5, 8, 7.	10·6
April	26·6 to 30·0	9, 6, 6, 5, 6, 11, 6, 6, 6, 7, 14, 5, 4, 6, 5, 5, 8, 11, 5, 4.	6·8
May	28·2 to 33·3	7, 8 . . .	7·5
June	31·2 to 34·2	4, 8, 4, 7	5·7
July	29·5 to 32·0	4, 5, 8	5·7
August	32·7 to 33·7	5, 8	6·5

IV. WINTER INTERVENING BETWEEN TWO OVIPOSITIONS

We were exceedingly fortunate in obtaining two most interesting records of oviposition by the same females, once before winter and again after winter (Table IX). These two females acquired wings in August-September, and laid their first cluster of eggs in October 1930, and after a period of 90 days and 125 days, laid their second clusters in January and February 1931. These two instances further indicate the influence of low temperature in prolonging the inter-oviposition period. Whether a similar phenomenon can occur in nature is worth investigating. Once again this observation proves that there is no diapause in the adult stage and that besides other factors, temperature is responsible for the control of processes connected with oviposition.

TABLE IX

Inter-oviposition period prolonged by the intervention of winter

Experiment No.	1st oviposition	2nd oviposition	Inter-oviposition period (days)
1	15th October 1930 .	17th February 1931	125
2	25th ,, ,, .	23rd January ,, .	90

From what has been stated above it is quite evident that in the same individual at the same temperature the period between different ovipositions may vary, as for instance from three to twenty-four days at 30°C. Undoubtedly the inter-oviposition period is determined by other factors, internal and external, although temperature is not without marked influence. It is evident that in case of a fall in temperature this period is lengthened, while at suitable temperatures successive batches of eggs may be laid at short intervals.

4. Number of ovipositions by a female

From their observations in cages Kunckel and Regnier admitted eleven successive ovipositions by the same female. Vosseler [1905] regards two ovipositions as not impossible. Bodenheimer was inclined to admit two ovipositions by a swarm in nature. Ballard and associates [1932] give six batches as the maximum.

An examination of Table V shows that at high temperatures, *i.e.*, 36°C. and 40°C., the total oviposition period was much shortened and the maximum number of egg clusters was only three, which were all laid within a fortnight. At 30°C., however, five clusters were recorded which were laid in about $1\frac{1}{2}$ months.

Numerous observations were made at room temperature (Table VI). The maximum number of egg-pods laid by the same female, that we have recorded, was eleven, from an over-wintered individual, which finished its oviposition before the laboratory temperature rose above 30°C. From June to August, however, when the laboratory temperature usually remained above 30°C., the number of oviposition was greatly reduced, the maximum being three. This confirms the results obtained in the constant temperature incubators.

5. Oviposition

I. OVIPOSITION AT HIGH SOIL TEMPERATURE

There is no previous record of observations on the influence of soil temperature on the behaviour of female in boring into the soil and ovipositing in it. To find out the highest soil temperature at which oviposition could take place the following experiment was performed:—

A rearing cage (Fig. 2) with three storeys was prepared. The uppermost portion (A) was 8 in. × 8 in. × 10 in., three sides and the top of which were of wire gauze. The fourth side was a glass door. The locusts were kept in this portion. The middle portion (B) had the same dimensions as the upper portion but all the four sides were enclosed with ply-wood sheets; in one of the sides holes were provided for inserting the thermometers (th). This portion was filled with sandy soil(s), for purposes of oviposition. The lowermost portion (C) was 5·5 in. × 5·5 in. × 7 in. and was made of 'tin'. One of its sides had two holes. The upper one (a) for the escape of steam and for replenishing the water lost through evaporation, and the lower one (b) carried a cork and a glass tubing which served to indicate the level of water in the tin.

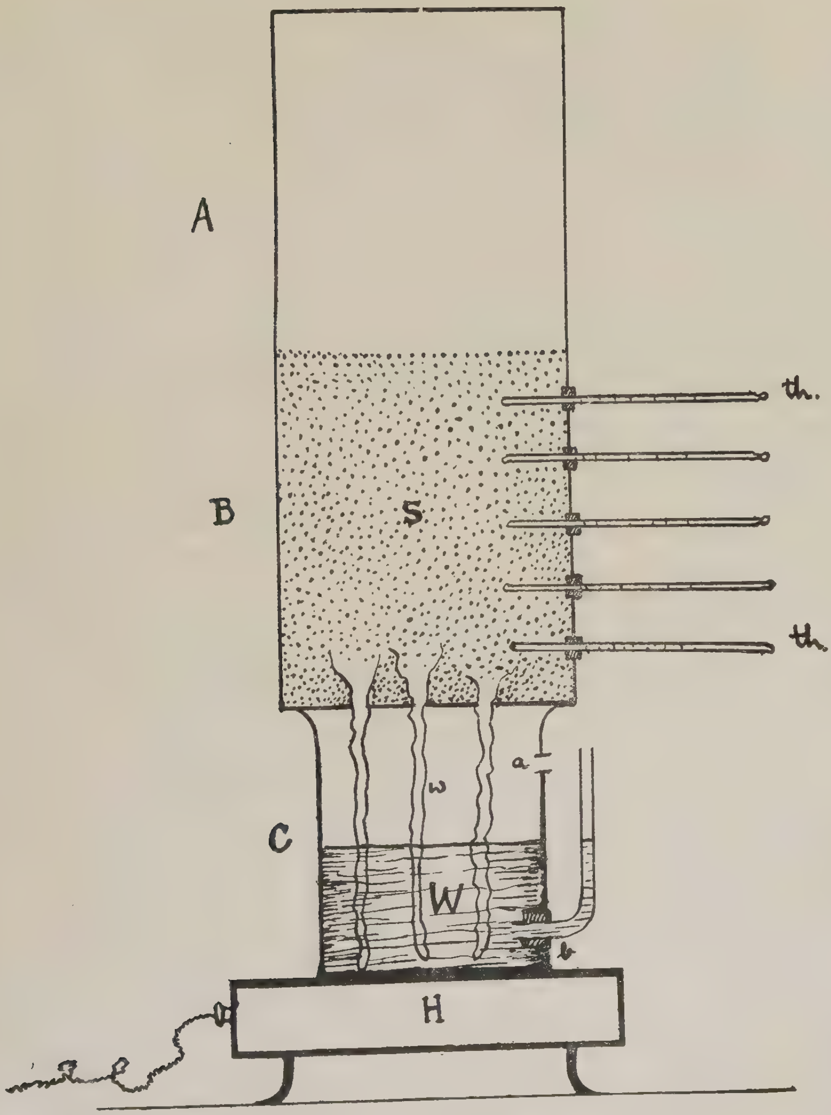

Fig. 2. Rearing cage.

Between the lower and the middle portions there was a wire-gauze partition supported by wooden frame-work. The soil in the middle portion was placed in constant contact with the water(W) in the lowest portion by means of cotton wicks(w). As the water in the soil evaporated, the loss of moisture was made good by water sucked up by capillary action through the wicks. The water was heated by an electric heater(H) placed at the bottom of the cage. Thus the soil was maintained at an appreciably higher temperature than the top portion A.

It was found that a female could bore into the soil when the surface temperature was 42°C., and the soil temperature at the depth of three inches, where the egg-pod was laid, was 48°C. None of these eggs, however, hatched out (Table X). It would be interesting to perform further experiments along these lines.

Table X

Oviposition at high soil temperature

Date of oviposition (1931)	Depth of bore in inches	Temperature in cage in Centigrade				Soil temperature at the depth of egg-pod at the time of oviposition (°C.)
		Air	Soil surface	Soil at 2·5 in.	Soil at 4·5 in.	
22nd June . . .	2·5	36	42	45·5	55	. .
12th August . . .	4	34·5	37·5	42·5	51·5	. .
26th ,, . . .	4	. .	. .	44	. .	45
21st September . .	. .	31·4	32·2	43·4	52·8	44
20th—21st Oct. . .	2·5	28·4	30·8	46·2	55·8	. .
23rd Oct. . . .	2·5	32·4	33	40·8	58·4	. .
27th Oct. . . .	3·2	29·8	30·4	41·2	51·8	. .
18th Nov. . . .	2·5	27·4	31·2	39	46·4	40
21st Nov. . . .	3·5	28·2	30·4	39·8	51·4	42·5
23rd Nov. . . .	3	. .	38	45	56	46
26th Nov. . . .	3	25	30	46·5	59	48
28th Nov. . . .	3·2	28	30	41	50	43·5
13th Nov. . . .	2·5	27	30	42	50	42

Note.—Eggs did not hatch in any case.

II. OVIPOSITION AT LOW SOIL TEMPERATURE

To study the influence of low soil temperature on oviposition the following experiments were performed:—

A wooden cage 24 in. × 24 in. × 12 in. was filled with sandy-loan soil upto six inches. In the centre of this cage a metallic jar about six inches in diameter and six inches in depth was buried in the soil. This was always kept filled with ice. This arrangement gave us a series of soil temperatures ranging from about 0°C., next to the ice jar, to 30°C., in the farthest corners of the cage. The temperature of the soil was recorded by a series of thermometers inserted at regular intervals from the cooling vessel, the bulbs being placed at 3-4 in.—the usual depth at which the eggs were laid. A number of mature pairs was placed in this cage. It was noticed that all the thirteen egg-pods laid were deposited in the four corners of the cage, *i.e.*, farthest from the cooling vessel (Fig. 3). In these places the temperature ranged from 25·5° to 28·8°C. The details of this experiment are given in Table XI.

TABLE XI

Oviposition at low soil temperature (*Figs. 3 & 4*).

Date of oviposition (1931)	Distance from centre (inches)	Depth to the bottom of pod (inches)	Temperature at the time of oviposition (°C.)
	Experiment 1		
2nd July	10	3·5	..
7th July	9·5	3·25	..
11th July	10·25	3	28
11th July	10·0	..	28·6
11th July	11	..	29
15th July	10·5	3·75	26
17th July	..	..	28
18th July	9·5	2·5	25·5
	Experiment II		
14th Aug.	7	2·7	21·5
14th Aug.	7	3·8	21·0
15th Aug.	7	..	20·0
19th Aug.	6·5	2	23·3

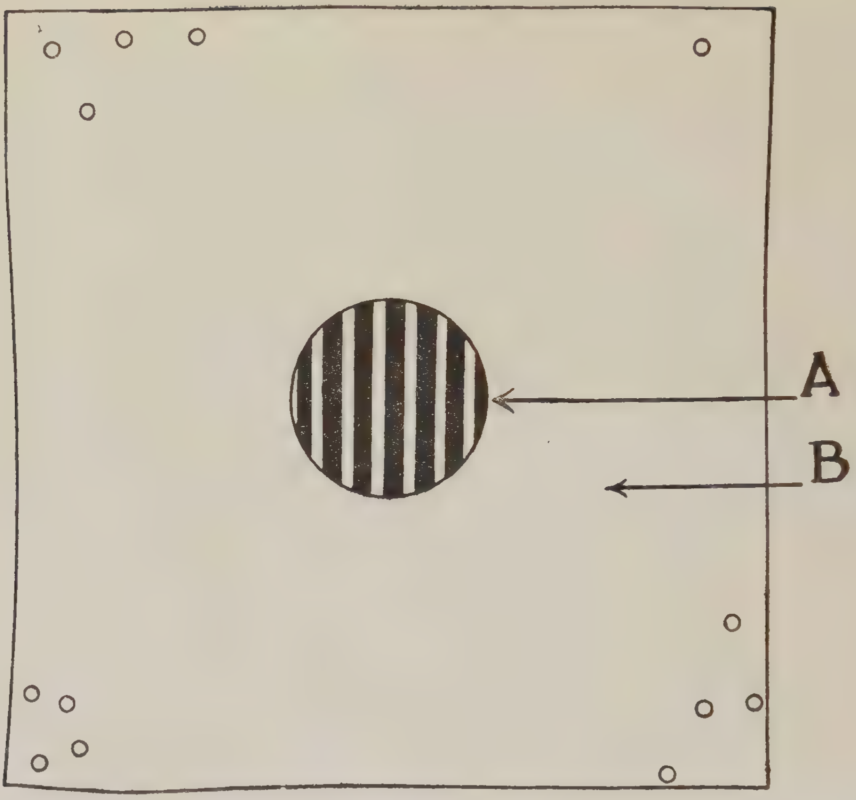

Fig. 3. Cross-section of the cool cage.
A = Cooling vessel, B = Soil available for oviposition.
O = Places where eggs were laid.

This experiment was further modified with a view to force the females to lay eggs at a still lower temperature. With this object access to the more distal parts of the soil was cut off by covering it with a tin sheet. Thus only a circular band of soil was left exposed (Fig. 4). In this case also the eggs were laid farthest from the cooling vessel along the circumference of the soil exposed. The lowest soil temperature at which we obtained eggs was 20°C. This would appear to be the lowest limit, as it approaches the developmental zero of the various stages of this insect. Further observations are, however, necessary to fix the lowest limit definitely.

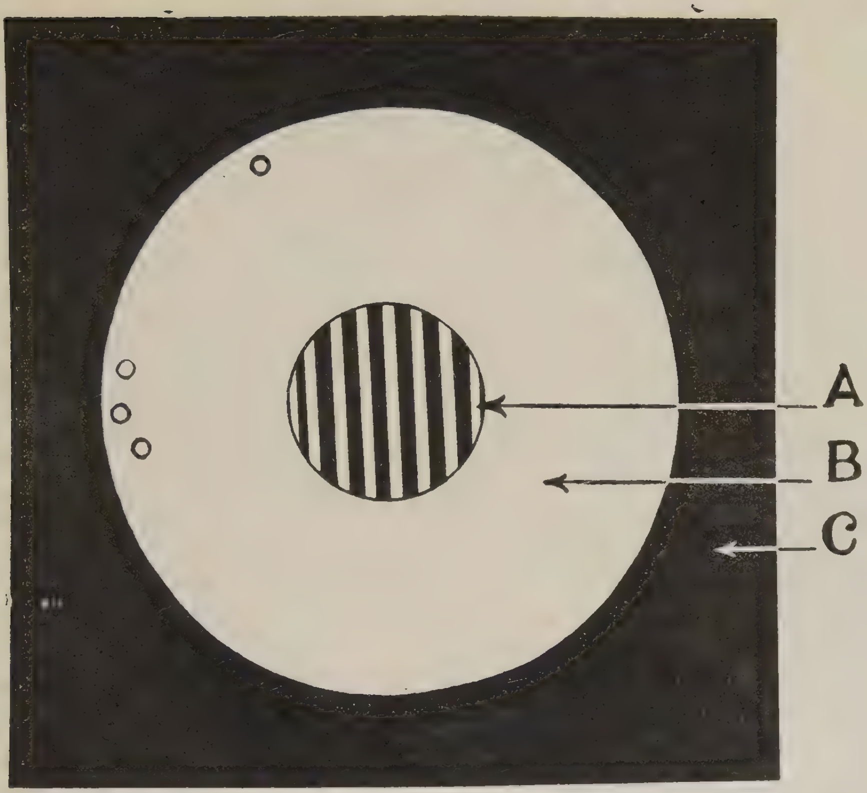

Fig. 4. Cross-section of cool cage (modified).
A = Cooling vessel. B = Soil available for oviposition.
C = Soil covered over with tin sheet.
O = Places where eggs were laid.

6. Incubation

The incubation period for the eggs of *Schistocerca gregaria* has been recorded by various investigators, and the available data are summarised below:—

Investigator	Country	Incubation period
Vosseler	South Africa	16—18 days.
Gough (1915)	Egypt	16—30 days.
Bucher (1915)	Palestine	4 weeks (28 days).
Regnier (1926)	..	16—40 days.
Telenga (1930)	..	3 weeks (21 days).
Bodenheimer (1930)	Palestine	30 days in Feb. and March, 14 days in May.

Observations of various investigators in the Punjab, under natural conditions, place the incubation period at three to four weeks in winter, and a fortnight in summer.

Ballard and others [1932] have given a statement of the incubation period of eggs laid during different months of the year which we quote below:—

Months of oviposition		Average incubation period (days)	Month of hatching
March		43	April—May
April		31	April—May
May		21	May—June
August		23	August—September
September		34	Sept.-Oct.-November
November (without winter diapause)		19	November
November	Winter egg diapause	106	February—March
December		95	March
January		79	March—April
February		67	April

Unfortunately no mention is made as to whether the cages were kept in a room or in the open. Nor is there any information concerning the temperature of the soil in which the eggs remained. It is, however, evident that these eggs remained under different conditions of temperature, and perhaps also of soil moisture.

It is known that soil-moisture deficiency prolongs the incubation period and in one of our experiments we have prolonged it to seventy days, though under the same conditions of temperature the normal incubation period was found to be only twelve days.

I. INCUBATION OF EGGS AT CONSTANT TEMPERATURE

The incubation of the eggs of the Desert Locust has been studied under constant temperatures. For this purpose freshly laid eggs were removed from the oviposition cages, washed in distilled water and placed in sterilized moist sandy soil, in glass tubes. These tubes were kept in incubators at different temperatures. In some cases the temperature was constant, while in certain other cases, such as the multiple incubator, it varied within a few degrees. Similarly there was variation in the temperature of the cool cage described above. Our data of incubation at different temperatures are not complete: we have had numerous failures in these experiments because of the fungi and nematodes attacking the eggs.

(*a*) *Threshold of development*

To determine the minimum temperature at which development of *Schistocerca gregaria* eggs could take place the following experiments were performed. Two batches of eggs laid on 28th Feb. 1934, at eleven and thirteen hours, by two different females, were left in the soil of the cage at room temperature (18-21°C.) till twelve hours the next day. On 1st March, 1934 they were taken out, washed with water and placed in dried sterilized soil, which was then moistened with sterilized water. Five eggs were placed in each tube and eleven tubes were set up. The mouths of the tubes were sealed with wax-paper and wax. These tubes were placed in different compartments of the multiple incubator at sixteen hours on 1st March, 1934. The incubator worked satisfactorily till 4th April, 1934, when the low-temperature incubator went out of order, and all the tubes in which hatching had not occurred were transferred to a constant temperature thermostat working at 35°C. The details of this experiments are given in Table XII.

TABLE XII

First set: the threshold of development of Schistocerca gregaria *eggs*

Reference No. L414/28th Feb. 1934. Eggs laid on 28th Feb. 1934. Experiment set up on 1st Mar. 1934.

Tube No.	Initial treatment			Subsequent treatment		Incubation period* (days)	No. of eggs	No. of hoppers	Remarks
	Temperature	Date of hatching	Incubation period (Days)	Date of transferring to 35°C.	Date of hatching				
1	20—21°C. .	2nd April .	32+1	...	...	32+1	5	4	Soil examined on 4th April 1934. 4 hatched eggs and one rotten.
2	,, .	2nd April .	32+1	...	...	32+1	5	5	...
3	,, .	2nd April .	31+1	...	...	31+1	5	1	Soil examined on 4th April 1934. One hatched egg and 4 plump yellowish brown undeveloped eggs
4	,, .	1st April .	31+1	...	...	31+1	5	5	...
5	18—19°C. .	...	...	4th April .	11th April	34+7+1=42	5	5	...
6	,, .	...	...	,, .	11th April 12th April	34+7+1=42 34+8+1=43	5	3 2	...
7	,, .	...	...	,, .	...	...	5	...	Soil examined on 17th April 1934. Eggs rotten with plenty of nematodes in the soil.
8	,, .	...	...	,, .	...	...	5	...	
9	16—17°C. .	...	...	,, .	15th April	34+11+1=46	6	5	Soil examined on 17th April 1934. Remaining eggs shrivelled.
10	,, .	...	...	,, .	15th April 16th April	34+11+1=46 34+12+1=47	6	4 2	...
11	,, .	...	...	,, .	15th April 16th April	34+11+1=46 34+12+1=47	6	3 3	...
12	,, .	...	...	,, .	15th April 16th April	34+11+1=46 34+12+1=47	6	5 1	...
13	13°C. (about)	...	...	,, .	15th April 16th April	34+11+1=46 34+12+1=47	5 5	1 4	...
14	,, .	...	...	,, .	15th April	34+11+1=46	5	3	Soil examined on 17th April 1934. Remaining two eggs with full grown dead larvae.
15	,, .	...	...	,, .	15th April 16th April	34+11+1=46 34+12+1=47	7	3 3	Soil examined on 17th April 1934. The remainng egg had rotted.
16	,, .	...	...	,, .	15th April 16th April	34+11+1=46 34+12+1=47	8	3 5	...

* NOTE.—In this column the first figure indicates the number of days the eggs were kept under the initial treatment , the second number indicates the days at the subsequent treatment and the third number, *i.e.*, (1) indicates the period passed at room temperature (18-21°C.) before the experiment.

TABLE XII—*contd.*

Second set: the threshold of development of Schistocerca gregaria *eggs*

Reference No. 416/28th Feb. 1934. Eggs laid on 28th Feb. 1934. Experiment set up on 1st Mar. 1934.

Tube No.	Initial treatment			Subsequent treatment			No. of eggs	No. of hoppers	Remarks
	Temperature (°C.)	Date of hatching	Incubation period (days)	Date of transferring to 35°C.	Date of hatching	Incubation period* (days)			
16	20—21°	1st April	31+1	...	...	31+1	5	5	...
15	,,	1st April	31+1	...	...	31+1	5	3	Soil examined on 4th April 1934. Three hatched and two rotten eggs.
14	,,	2nd April	32+1	...	...	32+1	4	4	...
13	,,	1st April	31+1	...	...	31+1	4	3	Soil examined on 4th April 1934. Three hatched eggs only.
12	18—19°	...	...	4th April	10th April	34+6+1=41	6	5	Soil examined on 17th April 1934. 5 hatched eggs and one egg which looked plump and yellowish without embryo.
11	,,	...	...	,,	11th April	34+7+1=42	4	4	...
10	,,	...	...	,,	...	...	4	...	Soil examined on 17th April 1934. The eggs contained full-grown but dead embryo.
9	,,	...	...	,,	12th April	34+8+1=43	5	5	...
8	16—17°	...	...	4th April	15th April	34+11+1=46	5	4	Soil examined on 17th April 1934. 4 hatched eggs and one rotten egg.
7	,,	...	...	,,	15th April	34+11+1=46	5	4	Soil examined on 17th April 1934. 4 hatched eggs and one plump but undeveloped egg.
6	,,	...	...	,,	16th April	34+12+1=47	4	4	...
5	,,	...	...	,,	17th April	34+13+1=48	5	5	...
4	13° (about)	...	...	4th April	15th April	34+11+1=46	5	5	...
3		...	...	,,	15th April	34+11+1=46	5	5	...
2		...	...	,,	15th April	34+12+1=47	6	4	Soil examined on 17th April 1934. 6 hatched eggs and 2 eggs with vermiform larvae that could not come above the soil.
1		...	...	,,	15th April 16th April	34+11+1=46 34+12+1=47	9 ...	3 6	...

---

* NOTE.—In this column the first figure indicates the number of days the eggs underwent the initial treatment, the second number indicates the number of days at the subsequent treatment and the third number *i.e.* (1) indicates the period passed at room temperature (18-21°C.) before the experiment.

Besides the above-mentioned two sets of experiments, three more sets on similar lines were arranged. Unfortunately none of the eggs in them, including the control, hatched.

At a temperature of 20-21°C. the incubation period was thirty-one to thirty-two days (*plus* one day at room temperature, 18-21°C.). At the other three temperatures, *i.e.*, 18°-19°C., 16°-17°C., and approximately 13°C., the eggs remained for thirty-four days without hatching. After this period the tubes were transferred to 35°C. It is interesting to note that in the case of tubes kept at 18°-19°C., the eggs hatched out after seven to eight days-incubation at 35°C., showing that some development had taken place at 18°-19°C. In case of the tubes at 16°-17°C., and 13°C., a period of eleven to thirteen days incubation at 35°C., was necessary for hatching. From this it is evident that no development had taken place at these low temperatures. We thus conclude that the threshold of development is somewhere between 17° and 18°C.

At 35°C., the normal period of incubation is twelve days (Table XIII). The additional time taken by tubes kept for thirty-four days at 18°-19°C., is equal to 7·2 days at 35°C. One may conclude therefore that about forty per cent of the development had taken place at 18°-19°C., before these eggs were transferred to 35°C. From this it may be calculated that the incubation period at 18°-19° or 18·5°C., would be:—

$$34 \times 5/2 = 85 \text{ days.}$$

(*b*) *Incubation period at constant temperatures*

The results of experiments on the incubation period at constant temperatures, controlled by electric thermostat, are given in Table XIII(A), and those at temperatures controlled by multiple incubator with a variation of approximately 1·5°C. are given in Table XIII(B). Time-temperature and temperature-rate curves based on Table XIII are shown in Fig. 5. The observations carried out in the multiple incubator are indicated by cross '×' on the index line. It will be noticed that while these crosses do not lie exactly on the index line, they follow more or less the same course, the variation being due to the less constant temperatures in this case. From these data we arrive at the following general conclusions:—

Below 20°C., we did not get any hatching although some development went on even at 18-19°C., as indicated by experiments on the threshold of development. The theoretical threshold of development (Fig. 5) lies at 16°C.

At a temperature varying between 20° and 21°C., the incubation period was thirty-one to thirty-two (+1) days, between 20·5° and 23·8°C., it was twenty-eight to thirty-one days, and between 25·5°C. and 28·8°C., the incubation period was eighteen to twenty-one days. At 33°C. and 35°C. constant it was twelve to thirteen days and at 40°C. it was about eleven days. The shortest incubation period recorded was nine days at a temperature varying between 43° and 46°C., in the multiple incubator. It may be stated that our multiple incubator did not work very satisfactorily and the temperature varied considerably. Ordinarily we did not get any hatching above 43°C., and the higher temperature of 46°C., in the above experiment must have been for a very short duration.

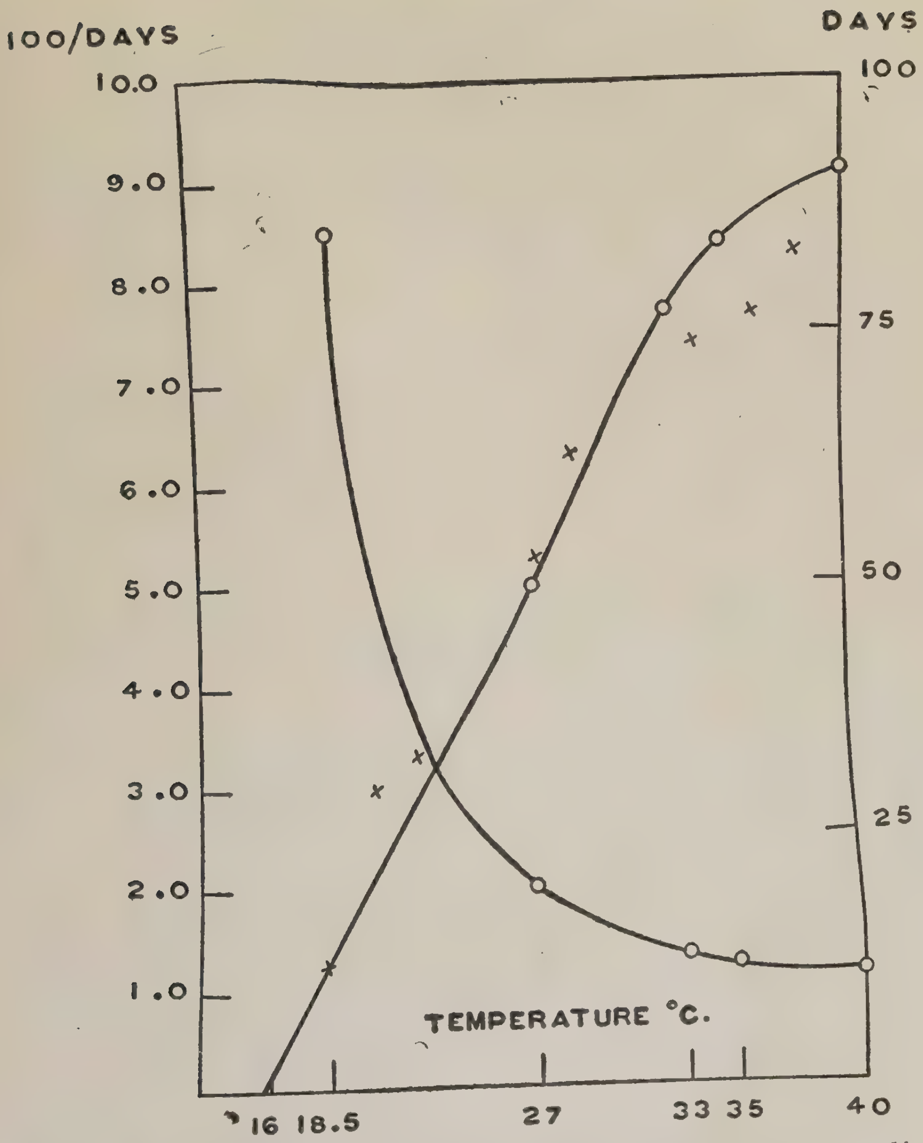

Fig. 5. Time temperature and temperature-rate curves of incubation period of *Schistocerca gregaria* eggs.

O = Observations from electric thermostat.

× = Observations from multiple incubator and the cool cage.

TABLE XIII

Incubation period at constant temperatures

(1931)

Reference No.	Temp. (°C.)	Date of oviposition	Date of hatching	Incubation period (days)	Mean period (days)	No. of hoppers hatched	Remarks
A.—Electric thermostat with a variation of about ±0·5°C.							
....	27	11th Dec.	31st Dec.	20	20·0	7	Eggs kept in moist soil in tube
Q31 (*b*) I	33	20th Aug.	2nd Sept.	13	..	..	Eggs exposed to 100 per cent humidity
Q31 (*a*) I	33	20th Aug.	2nd Sept.	13	..	..	Ditto
Q31 (*a*) III	33	26th Aug.	7th Sept.	12	13·0	3	Eggs kept in moist soil in tube
Q31 (*a*) I	35	20th Aug.	2nd Sept.	13	..	..	Eggs exposed to 100 per cent humidity
Q31 (*b*) I	35	20th Aug.	1st Sept.	12	..	..	Ditto
Q31 (*b*) III	35	26th Aug.	6th Sept.	11	..	4	Eggs kept in moist loam soil in tube
L9	35	16th Dec.	28th Dec.	12	12·0	5	Ditto
Q31 (*a*) I	37	20th Aug.	1st Sept.	12	..	..	Eggs exposed to 100 per cent humidity
Q31 (*b*) I	37	20th Aug.	1st Sept.	12	..	..	Ditto
Q35 II	37	24th Aug.	6th Sept.	13	..	..	Ditto
Q31 (*c*) III	37	26th Aug.	6th Sept.	11	..	4	Eggs kept in moist loam soil in tube
Q31 (*d*) III	37	26th Aug.	7th Sept.	12	12·0	4	Ditto
L13	40	13th Dec.	24th Dec.	11	11·0	8	Ditto

TABLE XIII—*contd.*

Incubation period at constant temperatures

Reference No.	Temperature (°C.)	Date of oviposition	Date of hatching	Incubation period (days)	Mean period (days)	No. of hoppers hatched	No. of eggs
B.—In multiple incubator and cool cage (the variation being about ± 1·5°C.)							
Cool Cage . .	22·2 ± 1·6 .	14th Aug. .	11th-12th Sep	28— 29	..	35	Full egg pod
,, . .	22·2 ± 1·6	14th ,, .	13th Sep. .	30	..	..	,,
,, . .	22·2 ± 1·6	15th ,, .	13th ,, .	29	..	..	,,
,, . .	22·2 + 1·6	19th ,, .	20th ,, .	31	29·0	..	,,
,, . .	27·2 ± 1·6	2nd July .	22nd July .	20	..	30	,,
,, . .	27·2 ± 1·6	7th ,, .	28th ,, .	21	..	17	,,
,, . .	27·2 ± 1·6	11th ,, .	29th ,, .	18	..	82	,,
,, . .	27·2 ± 1·6	11th ,, .	30th ,, .	19	..	71	,,
,, . .	27·2 ± 1·6	11th ,,	30th ,, .	19	..	71	,,
,, . .	27·2 ± 1·6	15th ,, .	2nd Aug. .	18	..	52	,,
,, . .	27·2 ± 1·6	17th ,, .	4th ,, .	18	..	33	,,
,, . .	27·2 ± 1·6	18th ,, .	7th July .	20	19·0	48	,,
9 . .	29·0 ± 1·0	16th Nov. .	2nd Dec. .	16	16·0	8	10
L2 . .	34·0 ± 1·0	5th Dec. .	20th ,, .	15	..	8	13
L8 . .	34·0 ± 1·0	5th ,, .	21st ,, .	16	..	3	13
L19 . .	34·0 ± 1·0	5th ,, .	17th Nov. .	12	14·0	7	10
L2 . .	36·5 ± 1·5	5th ,, .	18th Dec. .	13	..	12	13
L13 . .	36·5 ± 1·5	5th ,, .	18th ,, .	13	13·0	13	13
L19 . .	38·3 ± 1·2	5th Sep. .	17th Sep. .	12	12·0	5	10
L2 . .	42·0 ± 2·0	5th Dec. .	17th Dec. .	12	..	6	13
L3 . .	42·0 ± 2·0	5th ,, .	17th July .	12	12·0	7	13
L19*a* . .	44·5 ± 1·5	5th Nov. .	14th Nov. .	9	..	4	10
L19*b* . .	44·5 ± 1·5	5th ,, .	14th ,, .	9	9·0	6	10
...	18·5 ± 0·5	From the data on threshold of development (Table XII).			85·0	24	24
...	20·5 ± 0·5	Ditto			32·4	30	38

(c) *Vital limits for the eggs*

The eggs exposed to 10-15°C., during the night and above 20°C., during the day hatched out successfully. The low temperature completely inhibits embryonic development, but the embryo is not killed even if the low temperature prevails for several hours. Eggs exposed to a temperature of about 13°C., for thirty-four days retained their viability and when subsequently exposed to 35°C., hatched out in eleven to twelve days, which is the normal incubation period at that temperature. It is not possible to confirm the statement that exposure to low temperature accelerates development [Parker, 1930].

To determine the upper vital limit, one to two days old eggs were removed from the soil in which they had been laid, washed in distilled water, and placed for a definite period on moist sterilised cotton or sand at the required temperature, and then removed and incubated at 30-33°C. (Table XIV). These essentially preliminary experiments show that the eggs kept at 46°-46.5°C., for two hours retained their viability, while those exposed to 47°-47·5°C., for two hours did not develop. Again, an exposure of eigh thours to 46°-46·5°C., killed the eggs. Further observations are necessary to determine definite limits of temperature and duration of exposure.

TABLE XIV

The upper vital limit of temperature for the eggs of Schistocerca gregaria *1931*)

Reference No. L10
Date of oviposition . . . . . 18th Nov. 1931.
Date of removal and experiment . . . 19th Nov. 1931.

Reference No.	Date of oviposition	Date of experiment	No. of eggs	Temp. to which exposed (in °C.)	Period of exposure (hrs.)	No. of hoppers emerged
L8	24th Nov.	26th Nov.	10	48—47·5	24	..
Q1	1st ,,	2nd Sept.	4	48·5—47	4	..
L8	24th ,,	26th Nov.	10	48—47·5	2	..
L10	18th ,,	19th ,,	10	47·5—47	8	..
L10	18th ,,	19th ,,	10	47·5—47	2	..
L8	24th ,,	26th ,,	10	47—46·5	24	..
L8	24th ,,	26th ,,	10	47·5—47	2	..
QA7	31st Aug.	2nd Sept.	4	47—43	10	..
L10	18th Nov.	19th Nov.	10	46·5—46	8	..
L10	18th ,,	19th ,,	10	46·5—46	2	5
Q1	1st Sep.	2nd Sep.	4	46—45	2	3
Q1	1st ,,	2nd ,,	4	45—44	2	3
QA7	31st Aug.	2nd ,,	4	44—43	2	2
QA7	31st ,,	2nd ,,	4	42·5-41·5	3	3

11. INCUBATION PERIOD AT ALTERNATING TEMPERATURES

An experiment was conducted in which freshly laid eggs from the same egg cluster, were transferred into moist sandy loam in four different tubes. Tube No. 1 was kept at 37°C., throughout the incubation period. No. 2 was kept for two days at 25°C., and the remaining period at 37°C., tube No. 3 was kept for ten days at temperatures between 33° and 37°C., and the remaining period at 25°C., while tube No. 4 was placed for two days at 20°C., four days at 25°-27°C., and the remaining period at 33°-37°. The results are given in Table XV.

TABLE XV

Effect of alternating temperatures on incubation period

Ref. No. 35. Date of oviposition 23rd August 1931

Tube 1	Tube 2				Tube 3				Tube 4			
	Date	Time	Temp. (°C.)	Duration (hrs.)	Date	Time	Temp. (°C.)	Duration (hrs.)	Date	Time	Temp. (°C.)	Duration (hrs.)
37°C. constant	23rd Aug.	16·0	37	44	23rd Aug. .	16·0	37	92	23rd Aug.	16·8	20	40
	25th ,, .	12·0	25	48	27th ,, .	12·0	35	72	25th ,, .	8·0	25	52
	27th ,, .	12·0	37	240	30th ,, .	12·0	33	72	27th ,, .	12·0	27	48
					2nd Sept. .	12·0	25	120	29th ,, .	12·0	33	48
									31st ,, .	12·0	35	48
									2nd Sept. .	12·0	37	120
Date of hatching 5th Sep.	6th Sept.				7th Sept.				7th Sept.			
Total incubation period (days)—13	14				15				15			

The eggs took thirteen, fourteen, fifteen and fifteen days, respectively to hatch.

By arranging the duration (in days) of each tube under each temperature we get the following figures:—

Tube No.	30°—37°C.	25°—27°C.	20°C.	Total incubation period (days)
1	13	..	..	13
2	12	2	..	14
3	10	5	..	15
4	9	4	2	15

III. INCUBATION PERIOD UNDER VARYING TEMPERATURES IN BREEDING CAGES KEPT IN OPEN

To simulate natural conditions two breeding cages 9 in. × 9 in. × 18 in., the lower portion of which contained sandy-loam soil with glass on four sides and the upper portion surrounded by wire-gauze, were placed on the roof of the insectary building, after eggs had been laid. This experiment was conducted during August, 1931. Daily records of soil temperature at the place of egg-pod and air temperature inside the cage at 7 A.M., 12 noon and 6 P.M. were maintained. During day time these cages were exposed to the maximum solar heat and during night to minimum air temperatures. The incubation period in both cases was thirteen days. Field observations during this period showed that the incubation period was about eleven days. It is evident from the record that during certain portion of the day the eggs were exposed to a maximum soil temperature of 43·8°C. (Table XVI).

TABLE XVI

Temperature record (°C.) in cages kept in the open

Date (August)	Maximum soil temperature	(Cage No. 1 ; Date of oviposition, 15th August 1931)						Cage No. 2 ; (Date of oviposition, 16th August 1931)					
		7 A.M.		12 NOON		6 P.M.		7 A.M.		12 NOON		6 P.M.	
		Air	Soil	Air	Soil	Air	Soil	Air	Soil	Air	Soil	Air	Soil
16	35·5	..	..	42	..	36	39	..	..	..	..	34·5	36
17	44·4	30	29·5	39·5	41	39·5	43	30	30	39	40	38·5	39·5
18	42·2	29·8	29·2	39·8	40·8	30·5	33·2	29·8	29	38·5	38·2	30	30·2
19	39·4	28·5	27·8	38	39·8	32·2	33·8	28·5	27·8	37·2	38	32·2	32·8
20	41·6	28·6	27·8	39	40·8	38	40·8	28·5	28	38	39·5	37·8	39
21	34·4	26·2	25·2	36·2	37·2	36	38	26·2	25·5	36·2	35·5	36	37
22	41·6	27·0	26·5	38·2	39·2	40·8	41·8	28	27·8	36·5	36	40·2	38·8
23	41·1	28·5	28·0	40·5	41·2	36	39	28·8	29	40	38·5	36	37
24	38·8	28·5	28·5	40·5	40·2	33·5	34·8	28·5	28·8	40	39·5	33·5	35·2
25	43·3	27·2	27	38·8	40·5	37	38·5	27·8	27	38·8	38·5	37	39·5
26	43·8	28·8	28·8	41·2	42·8	39·2	40·5	28·8	28·2	41·0	42·0	39·5	40
27	41·1	26·0	26·8	40·2	39·5	35·2	37·2	26·2	26·4	39·5	37·0	35·8	34·5
28	..	27·2	26·8	37·0	38·0	..	..	27	27·5	36·8	36·5	35·8	35·5

Date of hatching—28th August 1931

Date of hatching—29th August 1931

IV INCUBATION PERIOD AT LABORATORY TEMPERATURE DURING DIFFERENT MONTHS.

Observations on the dates of oviposition and hatching were recorded in a very large number of cases kept at laboratory temperature. The results are presented in Table XVII, and the temperature record in Table XVIII.

TABLE

Incubation period (days) at room temp

Previous History : Hoppers of V stage collected from

January—March			February—April			March—April			April—May			May—June		
Date of			Date of			Date of			Date of			Date of		
Oviposition	Hatching	Incubation period	Oviposition	Hatching	Incubation period	Oviposition	Hatching	Incubation period	Oviposition	Hatching	Incubation period	Oviposition	Hatching	Incubation period
th Jan.	14th Feb.	36	2nd Feb. .	1st Apl. .	58	2nd Mar. .	27th Mar. .	25	1st Apl. .	19th Apl. .	18	4th May .	24th May .	20
			3rd ,, .	22nd Mar. .	47									
4th ,, .	11th ,, .	28	4th ,, .	24th ,, .	48	4th ,, .	2nd Apl.	29	1st ,, .	21st ,, .	20	9th ,, .	28th ,, .	19
3rd ,, .	11th Mar. .	47	6th ,, .	30th ,, .	52	4th ,, .	8th ,, .	35	1st ,, .	21st ,, .	20	28th ,, .	8th June .	11
7th ,, .	25th Feb. .	29	10th ,, .	1st Apl. .	50	7th ,, .	11th ,, .	35	2nd ,, .	18th ,, .	16	29th ,, .	11th ,, .	13
8th ,, .	25th Mar. .	56	11th ,, .	30th Mar. .	45	7th ,, .	8th ,, .	32	3rd ,, .	21st ,, .	18	29th ,, .	11th ,, .	13
0th ,, .	27th ,, .	56	12th ,, .	28th ,, .	44	11th ,, .	10th ,, .	30	4th ,, .	24th ,, .	20	29th ,, .	11th ,, .	13
0th ,, .	25th ,, .	54	14th ,, .	5th Apl. .	50	11th ,, .	6th ,, .	26	4th ,, .	25th ,, .	22	29th ,, .	11th ,, .	13
			16th ,, .	1st ,, .	44	15th ,, .	15th ,, .	31	4th ,, .	20th ,, .	16	30th ,, .	13th ,, .	14
			18th ,, .	28th Mar. .	38	15th ,, .	11th ,, .	37	5th ,, .	22nd ,, .	17	30th ,, .	15th ,, .	16
			19th ,, .	2nd Apl. .	41	16th ,, .	13th ,, .	28	6th ,, .	22nd ,, .	16	30th ,, .	13th ,, .	14
			21st ,, .	29th Mar.	35	17th ,, .	20th ,, .	34	6th ,, .	25th ,, .	19	30th ,, .	14th ,, .	15
			21st ,, .	2nd Apl. .	40	18th ,, .	16th ,, .	29	6th ,, .	25th ,, .	19			
			26th ,, .	2nd ,, .	35	21st ,, .	14th ,, .	24	6th ,, .	30th ,, .	24			
			28th ,, .	1st ,, .	32	23rd ,, .	18th ,, .	26	7th ,, .	23rd ,, .	16			
			28th ,, .	3rd ,, .	34	23rd ,, .	14th ,, .	22	10th ,, .	22nd ,, .	12			
						24th ,, .	22nd ,, .	29	10th ,, .	5th May .	25			
						24th ,, .	16th ,, .	23	13th ,, .	1st ,, .	18			
						24th ,, .	15th ,, .	22	16th ,, .	11th ,, .	25			
						25th ,, .	14th ,, .	20	28th ,, .	12th ,, .	14			
						26th ,, .	17th ,, .	22						
						26th ,, .	17th ,, .	22						
						28th ,, .	12th ,, .	15						
						28th ,, .	1st May .	34						
						29th ,, .	19th Apl. .	21						
						29th ,, .	18th ,, .	20						
						31st ,, .	19th ,, .	19						
						31st ,, .	18th ,, .	18						
						31st ,, .	19th ,, .	19						

II

ture during different months (1931)

swarm and adults bred one pair in each cage.

June—July			July—August			August—September			September			October—November		
Date of		Incubation period	Date of		Incubation period	Date of		Incubation period	Date of		Incubation period	Date of		Incubation period
osition	Hatching		Oviposition	Hatching		Oviposition	Hatching		Oviposition	Hatching		Oviposition	Hatching	
June .	21st June .	19	10th July .	20th July .	10	3rd Aug. .	15th Aug.	12	4th Sep. .	20th Sep. .	16	18th Oct. .	2nd Nov. .	15
,, .	15th . .	13	28th ,, .	10th Aug.	13	7th ,, .	20th ,, .	13	4th ,, .	20th ,, .	16	24th ,, .	8th ,, .	15
,, .	18th ,, .	14				8th ,, .	22nd ,, .	14				24th ,, .	15th ,, .	22
,, .	15th ,, .	11				10th ,, .	22nd ,, .	12						
,, .	18th ,, .	14				10th ,, .	22nd ,, .	12						
,, .	19th ,, .	14				15th ,, .	28th ,, .	13						
,, .	19th ,, .	14				26th ,, .	8th Sep. .	13						
,, .	17th ,, .	12												
,, .	17th ,, .	12												
,, .	17th ,, .	12												
,, .	17th ,, .	12												
,, .	17th ,, .	12												
,, .	19th ,, .	14												
,, .	16th ,, .	10												
,, .	23rd ,, .	14												
,, .	23rd ,, .	14												
h ,, .	26th ,, .	14												
h ,, .	8th July .	13												
h ,, .	6th ,, .	10												
h ,, .	12th ,, .	14												

TABLE XVIII

Insectary room temperature °C. (1931)

Period		Maximum temperature			Minimum temperature		
From	To	Highest	Lowest	Average	Highest	Lowest	Average
14th Jan. .	11th Feb. .	16·1	11·6	14·08	15·5	10·0	13·04
11th Feb. .	17th Mar. .	21·6	13·5	16·55	20·0	10·5	14·04
31st Mar. .	18th Apr. .	30·0	28·0	29·95	27·0	25·0	25·86
18th Apr. .	14th May .	35·0	29·0	32·57	30·0	26·0	27·67
6th June .	16th July .	37·0	27·0	33·63	34·4	24·4	30·02
16th July .	14th Aug. .	36·6	28·5	30·86	35·5	27·0	29·11
6th Aug. .	18th ,, .	36·1	33·3	34·13	35·5	32·7	31·80
18th ,, .	17th Sep. .	35·5	28·5	31·22	34·4	28·0	30·65
10th Sep. .	2nd Nov. .	26·3	22·4	23·28	24·1	21·4	22·30
2nd Nov. .	11th Dec. .	23·0	18·1	20·47	21·9	14·1	19·35

From January to the first week of March these cages were placed in the sun during the day and in the laboratory at night. Thus the egg-pods even laid at the same time were exposed to different temperatures. When the cages were placed in the sun, the eggs laid nearer the periphery of the cages received a greater quantity of heat; again the side of the cage facing the sun got hotter quicker. Perhaps all the egg-pods were not at the optimum soil moisture. For these reasons we find considerable variation in the incubation period of eggs laid at about the same time. Similar circumstances perhaps explain variations in Ballard's [1932] experiments. The average figures of each month are, however, quite significant.

In January-February the average incubation period was forty-three days in March 25·6 days, in April 18·7 days, from May to August eleven to fourteen days, in September sixteen days and in October 17·3 days. There was no oviposition in November and December.

During the summer months (May to August) the incubation period was eleven to fourteen days, which agrees with the incubation period at constant temperatures between 33° and 40°C.

It may be mentioned here that at Lyallpur, during January and February, oviposition and hatching would not have taken place if the cages had not been placed in the sun during day time. In all cases where the cages were left at the room temperature, no oviposition took place.

As already mentioned, Ballard and others [1932], working in Egypt, record the following incubation periods (days):—

November	106
December	95
January	79
February	67

It would appear that the soil temperature in these cages was below the developmental zero, most of the time. We do not agree with Ballard and his co-workers that the extended incubation period, which they obtained in some of their cages, during November-December, represented the winter diapause. We use the term 'diapause' in its true sense of a fixed rhythm [Uvarov, 1928]. It is interesting to note that in Ballard's experiments the eggs laid on November 6th, 1929, hatched after an incubation period of just nineteen days, while for those laid on November 24th, 1929, *i.e.*, eighteen days later, the incubation period was 116 days. As happened in our cages, Ballard's cages were also probably exposed to very different conditions of temperature and possibly humidity.

7. Duration of larval period

The duration of the larval period studied by different investigators in different countries has been given by Bodenheimer [1920] as follows: (To these we have added Ballard's figures):—

Author	Country	Larval duration (days)
Vosseler	East African Steppes	50
Do.	East African Mountains	60—70
King	Sudan	40—50
L'ellement	Algeria	44—53
Regiering	Morocco	40
Gough	Egypt	42—56
Bucher	Palestine	42
Regnier	....	37—40
Bodenheimer	Palestine	42
Ballard and others	Egypt	39—153

From this it appears that the minimum larval duration, so far observed, is thirty-seven days and maximum 153 days. During the course of our study we have seen that the duration of the hopper stages varies with the quality and quantity of food, temperature, humidity, etc. It is, therefore, quite conceivable that wide variations may occur in cage experiments. Numerous observations in the field show that under natural conditions the two broods have very different larval duration; the summer brood taking about three to four weeks only and the spring brood (progeny of over-wintered adults) requiring six to seven weeks. This evidently directly depends on temperature.

I. Duration of the larval stages at constant temperatures

Three sets of experiments were performed in which hoppers were reared at the following constant temperatures: 24°, 27°, 30°, 33°, 36°, and 40°C. The conditions of the experiment may be briefly described thus: The cages employed were cylinders, made of brass wire-gauze (100 meshes to an inch), six inches long and two inches in diameter. These cylinders were closed at one end, and at the other end they were provided with a split cork through which the leaf of the food-plant could be introduced into the cage. In all these experiments young cabbage plants growing in earthen pots served as food. The cages were placed over living plants in pots, and the pots with the cages kept in thermostats at the required temperature. The hoppers had. therefore, an abundant supply of food available. The stage and conditions of hoppers were recorded at 8 A.M. daily. The data regarding the duration of the various stages at different temperatures, and mortality are given in Table XIX, and summarized in Table XX. At most temperatures four different cages were under observation and the number of hoppers reared at each temperature was not less than thirteen and in some cages the number was nineteen. The uniformity in the duration of a particular stage at each temperature is very significant.

TABLE XIX

History of hoppers reared at constant temperatures

(Experiment I. Reference No. L 224.)

Date	Days	24°C.	24°C.	27°C.	30°C.	30°C.	33°C.	33°C.	36°C.	36°C.	36°C.	40°C.
11th Nov. 1932 .	0	I (3)	I (3)	I (3)	I (3)	I (3)	I (3)	I (3)	I (3)	I (3)	I (3)	I (3)
12th ,, .	1											
13th ,, .	2											
14th ,, .	3									II (3)		II (3)
15th ,, .	4						II (3)	II (3)	II (3)		II (3)	
16th ,, .	5				II (3)	II (3)						D (1)
17th ,, .	6			II (3)								III (2)
18th ,, .	7				D (1)				III (3)	III (3)	III (2)	
19th ,, .	8	II (3)					III (3)	III (3)				
20th ,, .	9		II (3)									
21st ,, .	10		D (1)		III (2)	III (3)						IV (2)
22nd ,, .	11			D (1)					IV (3)	IV (3)	IV (3)	
23rd ,, .	12			III (2)			IV (3)	IV (3)				
24th ,, .	13											
25th ,, .	14					D (1)					D (1)	V (2)
26th ,, .	15				IV (2)	IV (2)			V (3)	V (3)	V (2)	
27th ,, .	16	III (3)	III (2)							D (1)		
28th ,, .	17						V (3)	V (3)				
29th ,, .	18											
30th ,, .	19			IV (2)								
21st Dec. 1932	20				V (2)	V (2)						
2nd ,, .	21											A (2)

23rd Dec. 1932 .	22								A (3)	A (2)	A (2)	
4th ,, .	23											
5th ,, .	24							D (1)				
6th ,, .	25											
7th ,, .	26	IV (3)					A (3)	A (2)				
8th ,, .	27		IV (2)	D (1)								
9th ,, .	28			V (1)								
10th ,, .	29											
11th ,, .	30											
12th ,, .	31				A (2)	A (2)						
13th ,, .	32											
14th ,, .	33											
15th ,, .	34											
16th ,, .	35											
17th ,, .	36											
18th ,, .	37											
19th ,, .	38											
20th ,	39	V (3)										
21st ,, .	40		V (2)									
22nd ,, .	41											
23rd ,, .	42											
24th ,, .	43											
25th ,, .	44											
26th ,, .	45											
27th ,, .	46											
28th ,, .	47			A (1)								
29th ,, .	48											
30th ,, .	49											
31st ,, .	50											
1st Jan. 1933 . .	51											

TABLE XIX—*contd.*

Date	Days	24°C.	24°C.	27°C.	30°C.	30°C.	33°C.	33°C.	36°C.	36°C.	36°C.	40°C.
2nd Jan. 1933. .	52											
3rd ,, . .	53	D (1)										
4th ,, . .	54											
5th ,, . .	55											
6th ,, . .	56											
7th ,, . .	57											
8th ,, . .	58											
9th ,, . .	59	D (1)										
10th ,, . .	60											
11th ,, . .	61											
12th ,, . .	62	A (1)	A (2)									
Duration of hopper stages in days.	...	62	62	47	31	31	26	26	22	22	22	21

NOTE.—Roman numbers represent instars of the hoppers.
Arabic numbers in ( ) represent the number of hoppers in the cage.
D-Died, and figure in ( ) represents number dead.
A-Adult, and figure in ( ) represents their number.

TABLE XIX—*contd.*

History of hoppers at different constant temperatures

(Experiment II. Reference No. P74)

Date	Days	24°C.	27°C.	30°C.	33°C.	36°C.	40°C.
14th Jan. 1933	0	I (3)	I (3)	I (3)	I (3)	I (3)	I (3)
15th ,,	1						
16th ,,	2	D (1)					
17th ,,	3			D (1)		II (3)	II (3)
18th ,,	4			II (2)	II (3)		
19th ,,	5						
20th ,,	6		II (3)			III (3)	III (3)
21st ,,	7						
22nd ,,	8	II (2)			III (3)		
23rd ,,	9			III (2)			D (1)
24th ,,	10					IV (3)	IV (2)
25th ,,	11						
26th ,,	12		III (3)		IV (3)		
27th ,,	13						
28th ,,	14			IV (2)		V (3)	V (2)
29th ,,	15						
30th ,,	16	III (2)					
31st ,,	17				V (3)		
1st Feb. 1933	18		D (1)				
2nd ,,	19		IV (2)				
3rd ,,	20			V (2)			

TABLE XIX—*contd.*

Date	Days	24°C.	27°C.	30°C.	33°C.	36°C.	40°C.
4th Feb. 1933 .	21					A (3)	A (2)
5th ,, . .	22						
6th ,, . .	23						
7th ,, . .	24						
8th ,, . .	25						
9th ,, . .	26				A (3)		
10th ,, . .	27	IV (2)	V (2)				
11th ,, . .	28						
12th ,, . .	29						
13th ,, . .	30						
14th ,, . .	31			A (2)			
15th ,, . .	32						
16th ,, . .	33						
17th ,, . .	34						
18th ,, . .	35						
19th ,, . .	36						
20th ,, . .	37						
21st ,, . .	38						
22nd ,, . .	39	D (1)					
23rd ,, . .	40	V (1)					
24th ,, . .	41						
25th ,, . .	42						
26th ,, . .	43						
27th ,, . .	44						

TABLE XIX —*contd.*

Date	Days	24°C.	27°C.	30°C.	33°C.	36°C.	40°C.
28th Feb 1933 . .	45						
1st Mar. 1933 . .	46		A (2)				
2nd ,, . .	47						
3rd ,, . .	48						
4th ,, . .	49						
5th ,, . .	50						
6th ,, . .	51						
7th ,, . .	52						
8th ,, . .	53						
9th ,, . .	54						
10th ,, . .	55						
11th ,, . .	56						
12th ,, . .	57						
13th ,, . .	58						
14th ,, . .	59						
15th ,, . .	60						
16th ,, . .	61						
17th ,, . .	62						
18th ,, . .	63	A (1)					
Duration of hopper stages (days).	. .	63	46	31	26	21	21

TABLE XIX—*contd.*

History of hoppers at different constant temperatures

(Experiment III. Reference No L 276)

Date	Days	24°C.	27°C.	30°C.	33°C.	36°C.	40°C.
16th Jan. 1933 . .	0	I (7)	I (7)	I (7)	I (7)	I (7)	I (7)
17th ,, . .	1	D (1)	D (2)				D (1)
18th ,, . .	2						
19th ,, . .	3					II (7)	II (6)
20th ,, . .	4				II (7)		
21st ,, . .	5			II (7)			
22nd ,, . .	6		II (5)			III (7)	III (6)
23rd ,, . .	7						
24th ,, . .	8	II (6)			D (2)		
25th ,, . .	9	D (2)		III (7)	III (5)		
26th ,, . .	10					IV (7)	IV (6)
27th ,, . .	11						
28th ,, . .	12		D (1)			D (1)	
29th ,, . .	13		III (4)		IV (5)	D (1)	D (1)
30th ,, . .	14			IV (7)		V (5)	V (5)
31st ,, . .	15						
1st Feb. 1933 . .	16						
2nd ,, . .	17	III (4)					
3rd ,, . .	18				V (5)		
4th ,, . .	19						D (1)
5th ,, . .	20		IV (4)	V (7)			
6th ,, . .	21					A (5)	A (4)

TABLE XIX—*contd.*

Date	Days	24°C.	27°C.	30°C.	33°C.	36°C.	40°C.
7th Feb. 1933 . .	22						
8th ,, . .	23						
9th ,, . .	24			D (1)			
10th ,, . .	25						
11th ,, . .	26						
12th ,, . .	27	D (1)			A (5)		
13th ,, . .	28	IV (3)					
14th ,, . .	29		V (4)				
15th ,, . .	30						
16th ,, . .	31			A (6)			
17th ,, . .	32						
18th ,, . .	33						
19th ,, . .	34						
20th ,, . .	35						
21st ,, . .	36						
22nd ,, . .	37						
23rd ,, . .	38		D (1)				
24th ,, . .	39						
25th ,, . .	40						
26th ,, . .	41	V (2)					
27th ,, . .	42						
28th ,, . .	43						
1st Mar. 1933 . .	44						
2nd ,, . .	45						
3rd ,, . .	46						

TABLE XIX—*contd.*

Date	Days	24°C.	27°C.	30°C.	33°C.	36°C.	40°C.
4th Mar. 1933 . .	47		A (3)				
5th ,, . .	48						
6th ,, . .	49						
7th ,, . .	50						
8th ,, . .	51						
9th ,, . .	52						
10th ,, . .	53						
11th ,, . .	54						
12th ,, . .	55						
13th ,, . .	56						
14th ,, . .	57						
15th ,, . .	58						
16th ,, . .	59						
17th ,, . .	60						
18th ,, . .	61						
19th ,, . .	62						
20th ,, . .	63						
21st ,, . .	64	A (2)					
Duration of hopper stages in days.	..	64	47	31	27	21	21

TABLE XX

Summary of experiments set out in Table XIX

Temperature (°C.)	Duration of each instar (days)					Total duration in hopper stage (days)	Serial No. of experiments	No. of hoppers in each experiment	No. reaching the adult stage	Mortality (Per cent)
	I	II	III	IV	V					
24 . .	8-9	7-9	10-11	13	21-23	62-64	1 2 3 4	3 3 3 7	1 2 1 2	63
27 . .	6	6-7	7	8-9	18-19	46-47	1 2 3	3 3 7	2 1 3	54
30 . .	4-5	4-5	4-5	5-6	11	31	1 2 3 4	3 3 3 7	2 2 2 6	25
33 . .	4	4-5	4	5	9	26-27	1 2 3 4	3 3 3 7	3 2 3 5	19
36 . .	3-4	3-4	4	4	7	21-22	1 2 3 4 5	3 3 3 3 7	3 2 2 2 5	37
40 . .	3	3	4	4	7	21	1 2 3	3 3 7	2 2 4	38

A second series of experiments was arranged in which hoppers were reared in glass jars covered with muslin, and were examined four times during the day, *i.e.*, at 7.0, 12.0, 16.0 and 21.0 hours, when food was changed, thereby securing a fairly high degree of accuracy regarding the exact time of moulting. In Table XXI the period under each stage is given as the minimum period of the stage *plus* half of the doubtful period.

TABLE XXI

Duration of larval instars at constant temperatures (1932)

Temperature (°C.)	Ref. No.	Date of hatching	I stage period	II stage period	III stage period	IV stage period	V stage period	Total larval life
			hrs.	hrs.	hrs.	hrs.	hrs.	Days hrs.
25	L 12	12th Jan. .	163·5					
	L 33	17th Jan. .						
			151·5	D				
			151·5					
			168					
	L 16	29th Jan. .	187	192	232·5			
			187	208·5	216			
			203·5	216	. .			
			211		. .			
			218·5		. .			
	L 44	2nd Feb. .	156	192	192	292·5	487·5	56 . .
			160	192	192	292·5	. .	
			160	192	192	. .	. .	
			180	172·5	. .	. .	. .	
27	L 12	12th Jan. .	120	127·5	136·5	208·5	499·5	45 9
			136·5	127·5	156	220·5	. .	
	L 34	15th Jan. .	101	. .	. .	. .	. .	

TABLE XXI—*contd.*

Temperature (°C.)	Ref. No.	Date of hatching	I stage period	II stage period	III stage period	IV stage period	V stage period	Total larval life	
			hrs.	hrs.	hrs.	hrs.	hrs.	Days	hrs.
	L 44	2nd Feb. .	124·5	132	. .	. .	. .		
			129	144	. .	. .	. .		
			139	144	. .	. .	. .		
30	L 12	12th Jan. .	96	120	112·5	144	259·5	30	9
			96	151·5	96	136·5	256·5	30	14
		17th Jan. .	96	107·5	96	144	271·5	30	0
33	L 33	17th Jan. .	96	72	64·5	115	187	22	5
			96	72	72	120	247	24	5
			96	79·5	88·5	127	. .		
			96	79·5	105	. .	. .		
	L 33	17th Jan. .	84	91·5	100	100	183	23	5
			96	88·5	91·5	100	192	23	14
	L 21	22nd Jan.	96	96	108	108	. .		
36	L 12	12th Jan. .	74·5	64·5	96	84	156	20	0
			74·5	64·5	96	84	168	20	9
			74·5	81	79·5	84	172·5	20	14
	L 21	22nd Jan. .	79	. .	. .	. .	. .	. .	. .
	L 44	2nd Feb. .	76·5	60	84	72	172	19	14
			76·5	67·5	76·5	76·5	203	21	6
			76·5	67·5	81	91·5	. .	. .	. .
			76·5	76·5	96	. .	. .	. .	. .
37	L 33	17th Jan. .	60	67·5	88·5	79·5	172·5	19	9
			64·5	67·5	84	88·5	168	19	14

TABLE XXI—*contd.*

Temperature (°C.)	Ref. No.	Date of hatching	I stage period	II stage period	III stage period	IV stage period	V stage period	Total larval life	
			hrs.	hrs.	hrs.	hrs.	hrs.	Days	hrs.
			64·5	67·5	91·5	81	192	20	14
			64·5	72	87	81	216	21	14
			..	79·5	88·5	91·5	..	..	..
	L 16	26th Jan. .	..	..	..	..	..	20	0
	L 56	13th Feb. .	83·5	67·5	76·5	96	168	20	14
			83·5	67·5	76·5	96	175·5	21	0
40	L 12	12th Jan. .	74·5	64·5	103	72	184·5	21	0
			74·5	81·5	87	81	..	..	..
	L 33	17th Jan. .	67	64·5	67·5	100	151·5	19	0
			67	64·5	72	103	151·5	19	5
			67	64·5	77·5	108	172·5	20	14
	L 12	19th Jan. .	67	72	84	84	204	21	7
			67	79·5	81	103	..	..	..
	L 44	2nd Feb. .	64·5	87	76·5	84	184	20	14
			64·5	87	76·5	..	..	..	..
			64·5	91·5	72	132	..	..	..
			64·5	91·5	76·5	..	..	..	..

The results obtained may be summarised as follows:—

20°C. and below.—Hoppers could not complete their development below 20°C. Freshly hatched hoppers lived as long as thirty-one days at 20°C., and died without moulting. They ate very little food and the original body colour (green or black) darkened very much. It is proposed to investigate the influence of this range of temperature on the hoppers of different stages.

21°-25°C.—Development took place very slowly and the death rate was enormous. At 21°C., the hoppers took thirteen to sixteen days in each of the first and second stages, but could not be bred further.

Out of 124 hoppers kept for breeding, in twenty-one batches, at this range of temperature, only seven acquired wings, taking fifty-six days at 25°C., and sixty-one to sixty-three days at 24°C. during the larval period.

At 27°C., the larval duration was forty-five to forty-seven days.

At 30°C., the average duration of the total larval life was thirty to thirty-one days. Bodenheimer [1930] also bred freshly hatched larvae in a thermostat at 30°C., but the results obtained by him do not agree with ours and for facility of comparison we give them below:—

	I instar	II instar	III instar	IV instar	V instar	Total larval period
	days	days	days	days	days	days
Bodenheimer's.	7	13	7	6	10	43
At Lyallpur .	4-5	4-5	4-5	5-6	11	31

At 33°C., the larval duration was twenty-two to twenty-seven days; and at 36°C., twenty to twenty-one days. Further rise in temperature did not shorten the larval duration, so that at 37°C. and 40°C., it was almost the same as at 36°C. This represents the range of temperature at which *Schistocerca gregaria* has the minimum larval duration of nineteen to twenty-one days.

44°C.—When the temperature was raised to 44°C., the larval duration was distinctly prolonged and the death rate increased enormously. Out of forty-four hoppers kept for breeding, in twelve different batches, at this temperature, only one acquired wings in twenty-seven days. Incidentally it may be mentioned that at this temperature the hoppers ate very little, appeared excited and lost their black markings.

For the calculation of the thermal constant we have the following data:—

Duration of the hopper stage at 25°C. . =56 days.
Duration of the hopper stage at 36°C. . =20 days.
Therefore (25-x) 56 . . . . . = (36-x) 20.
x (Developmental zero) . = 18·9°C.
Thermal constant . . . . . . = 342.

In the following table (Table XXII) we compare the calculated figures with the empirical ones.

TABLE XXII

The empirical and calculated figures for larval duration of Schistocerca gregaria.

Temperature (°C.)	Empirical duration (days)	Calculated larval duration (days)	Deviation of calculated figures from the empirical (Per cent)
25	56	56	0·0
27	42·2	45·3	7·3
30	30·8	30·2	—1·9
33	24·2	24·3	0·4
36	20	20·4	2·0

When one takes into consideration the fact that besides temperature there are other factors which influence duration in the hopper stage, such as food—quality and quantity—and humidity, etc., one is forced to admit that the approach of the empirical figures to the calculated figures is very significant.

The time-temperature and temperature-rate curves for the larval duration are shown in Fig. 6. The points expressing the index of development fit very closely on a straight line. The theoretical threshold of development lies between 18 and 19°C.

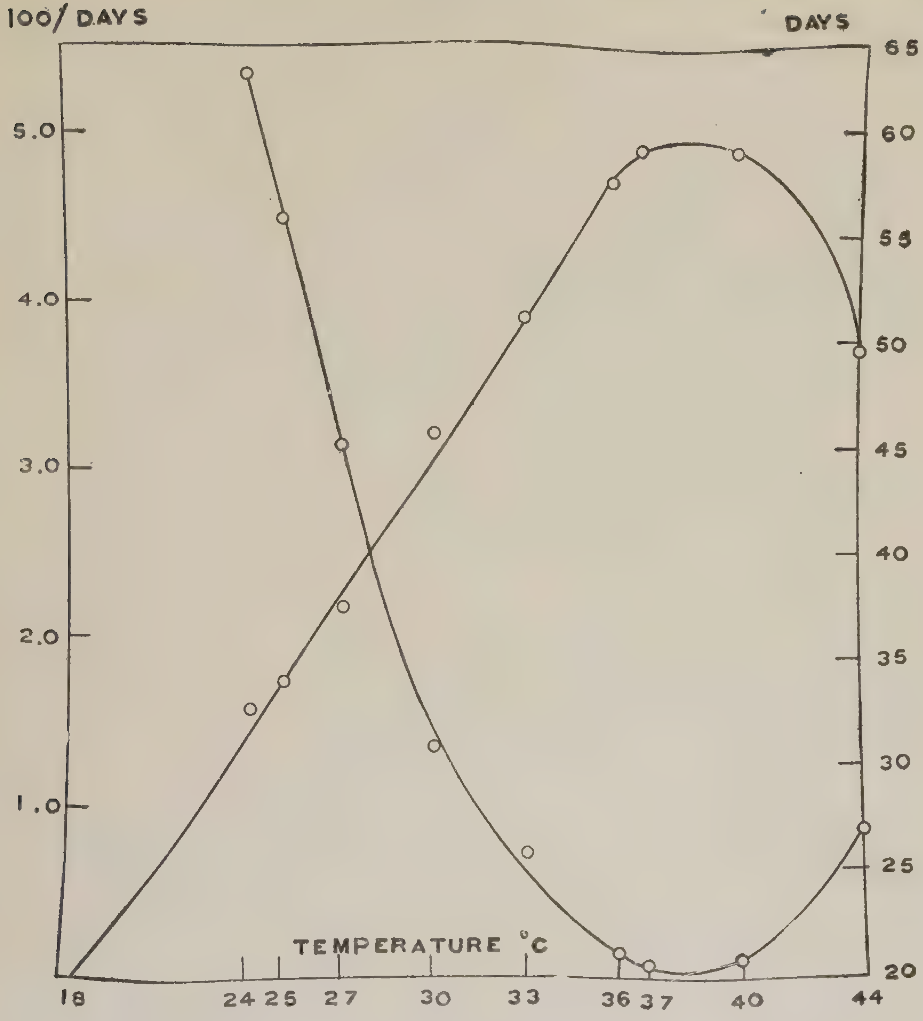

Fig. 6. Time-temperature and temperature-rate curves of larval period of *Schistocerca gregaria*.

II. Upper vital limit.

A number of observations were carried out by rearing hoppers at 46°C. As it was impossible for hoppers of any stage to moult at this temperature, freshly hatched and freshly moulted hoppers in various stages were exposed singly in each jar. Food was changed five times every day—at seven hours in the morning, three times during the day, and at twenty-one hours at night. Of the twenty-one hoppers under observation not a single one moulted. Table XXIII gives the details of these experiments. At this temperature the hoppers of the first stage lived as long as eight days and nineteen hours, those of II stage for four days, and those of III and V stages for six days and sixteen hours without moulting. The hoppers at this temperature are too much excited and hardly take any food.

TABLE XXIII

Duration of life of hoppers at 46°C.

(In each jar a single hopper was kept.)

Stage	No. of observations	Experiment started		Died		Period	
		Date (1932)	Time	Date (1932)	Time	Days	Hrs.
I (Freshly hatched)	1	29th Feb.	16·0	2nd Mar.	7·0	1	15
	2	29th ,,	16·0	6th ,,	13·0	5	21
	3	1st Mar.	10·0	4th ,,	7·0	2	21
	4	6th ,,	12·0	15th ,,	7·0	*8*	*19**
II (Freshly moulted).	1	4th ,,	12·0	6th ,,	13·0	2	1
	2	4th ,,	12·0	6th ,,	13·0	2	1
	3	8th ,,	15·0	9th ,,	16·0	1	1
	4	15th ,,	12·0	17th ,,	7·0	1	19
	5	17th ,,	10·0	21st ,,	10·0	*4*	*0*
III (Freshly moulted).	1	4th ,,	12·0	5th ,,	16·0	1	4
	2	4th ,,	12·0	5th ,,	16·0	1	4
	3	8th ,,	15·0	15th ,,	7·0	*6*	*16*
V (Freshly moulted).	1	4th ,,	12·0	5th ,,	7·0	0	19
	2	4th ,,	12·0	5th ,,	7·0	0	19
	3	4th ,,	12·0	5th ,,	..	0	21
	4	4th ,,	12·0	5th ,,	..	0	19
	5	8th ,,	15·0	9th ,,	12·0	0	21
	6	15th ,,	12·0	16th ,,	7·0	0	19
V (Freshly moulted).	1	4th ,,	12·0	5th ,,	21·0	1	9
	2	8th ,,	15·0	15th ,,	7·0	*6*	*16*
	3	15th ,,	12·0	16th ,,	7·0	0	19
Adult (male)	1	10th ,,	11·0	12th ,,	7·0	1	20

NOTE.—None of the hoppers in these experiments moulted.

* Figures in *italics* indicate the longest duration of life.

Thus at 46°C., the larvae of *Schistocerca gregaria* are not able to develop and moult. At optimum temperature the hoppers of the first four stages moult to the next stage within three to four days while at 46°C. they lived for more than this period without moulting.

Thus we find that 46°C. represents the upper vital limit of development for the larvae of *Schistocerca gregaria*.

III. DURATION OF THE HOPPER STAGES AT LABORATORY TEMPERATURE

The duration of each instar and the total hopper period at room temperature for every fortnight from March to October, are given in Table XXIV, and the room temperature record in Table XXV. The total hopper period is expressed in two columns:—(1) average duration of hopper stages, *i.e.*, when half of the hoppers of a batch acquired wings, and (2) shortest duration, *i.e.*, the time taken by the 1st individual of the batch to acquire wings.

TABLE XXIV

Duration of larval instars (days) for hoppers hatched during different months (1931) and bred at room temperature

Period of hatching (Date and month) 1932	I stage	II stage	III stage	IV stage	V stage	Total larval period	
						Average	Shortest
19th—29th Mar. . .	7·2	4·4	6·4	9·6	10·7	39·8	34·8
1st—15th April . .	7·5	6	6·1	6	9·8	35·7	33
16th—30th ,, . .	5·2	5	5·7	7	9	31·5	30·1
2nd—11th May . .	4·8	4·8	6·4	5·8	9	32·2	31·2
19th—31st ,, . .	4·4	4·7	6·2	7·1	8·7	31·5	31
1st—17th June . .	4·7	4·6	5·7	5·7	8·6	29·5	27·7
6th—15th July . .	4·6	4·7	6·1	6	8·1	29·3	27·8
18th—28th ,, . .	5·3	5·2	5·5	5·2	8	29·7	29·2
10th—29th Aug. . .	5·5	6·5	6·6	6·8	11·2	36·7	32·3
3rd—30th Sept. . .	6	6·2	6·5	6·5	10·2	35·5	32·7
23rd—31st Oct. . .	18·6	33 One hopper moulted and entered III instar: rest died in II stage after 30-44 days.					
3rd—13th Nov. . .	20·2	Died after living for 19-21 days in II stage.					
17th—20th ,, . .	25	One hopper moulted and entered II instar. rest died in I instar after living for 36 days.					

TABLE XXV

Record of room temperature °C. (1931).

Period	Maximum temperature		Minimum temperature	
	Highest	Lowest	Highest	Lowest
March	29·0	15·5	27·0	14·4
April	33·0	28·0	30·0	28·0
May	35·5	25·0	31·0	22·5
June	37·2	30·5	33·7	27·7
July	37·7	27·7	34·4	24·4
August	36·1	28·0	35·5	28·0
September	33·5	28·5	31·6	28·0
October	31·3	23·5	31·9	21·6

It will be observed that the individual instars as well as the total duration vary with temperature. During March the larval duration was forty days. As the temperature rose the duration shortened, the minimum duration recorded at laboratory temperature being twenty-four days for the hoppers hatched on 10th July 1932. During this period the temperatures recorded were:—

Highest maximum 35·5°C. Highest minimum 32°C.

Lowest maximum 33°C. Lowest minimum 28·5°C.

The larval duration again began to increase in August reaching thirty-eight days in September, Hoppers hatched in October and kept at room temperature could not complete their life cycle. They took sixteen to twenty days in I stage, and twenty-one to thirty-three days in II stage, and the majority of them died before the 2nd moult.

The hoppers hatching early in November were able to pass through only the 1st moult taking, on an average, twenty days in I stage. All of them died before the 2nd moult, living for another tewenty days in II stage.

The hoppers hatching at the end of November could not moult even once and died after living for thirty-six days in I stage.

IV. DURATION OF LARVAL STAGES IN THE HOPPERS CAGED ON PLANTS IN THE OPEN DURING WINTER (FEBRUARY—MARCH)

A number of experiments were started by rearing hoppers in muslin cages on living plants growing in the fields. Only in one case did the hoppers exposed to these conditions reach the adult stage. Details of the observations are as follows:—

The hoppers which had hatched on 12th October, 1932 were caged on a cotton plant in a muslin cage. They were transferred to a cabbage plant on 27th December. These hoppers remained at suitable temperature during the warmer part of the day only, and throughout the night and during the greater portion of the day the temperature remained below the development zero. This was particularly so during the III and IV stages. These two hoppers acquired wings on 22nd March, 1933, *i.e.*, after 161 days. This interesting observation shows the influence of temperature in prolonging the hopper stages and the possibility of the locust passing winter in the nymphal stages.

Ballard and co-workers have recorded a similar case and it is a happy coincidence that the period of their experiment synchronises with that of ours, and further the temperatures at which the two experiments were conducted were more or less the same (Table XXVI). It is, however, necessary to make it quite clear that both in our experiments and in Ballard's observations, the temperatures given are not the temperatures inside the cages but are taken from the meteorological records of the stations. In both cases the mean maximum and mean minimum temperatures for the different months are given, and evidently on certain days the temperature was higher than the mean maximum. These two experiments carried out in two different countries, during two different years, giving almost identical results are very significant and prove the great influence of temperature on the duration of the life of the Desert Locust hoppers.

TABLE XXVI

Comparison of larval duration at Lyallpur and in Egypt

Hatching	1st moult	I stage (days)	2nd moult	II stage (days)	3rd moult	III stage (days)	4th moult	IV stage (days)	5th moult	V stage (days)	Total nymphal life (days)
1. Lyallpur. Reference No. P 30.											
12th Oct. 1932 .	24th Oct.	12	6th Nov.	13	16th Dec.	40	26th Feb. 1933.	72	22nd Mar.	24	161
		Oct.	Nov.		Dec.	Jan.	Feb.		March.		
Temperature °C.	Mean max..	32·7	28·6		20·8	17·4	22·8		27·9		
	Mean min.	14·6	6·4		4·9	2·3	6·9		11·5		
2. Ballard (Egypt). Reference No. Cage No. 11.											
16th Oct. 1928 .	28th Oct.	12	10th Nov.	13	23rd Nov.	13	16th Jan. 1929.	54	18th Mar.	61	153
		Oct.	Nov.		Dec.	Jan.	Feb.		March.		
Temperature °C.	Mean max.	28·5	25·9		21·1	18·9	20·2		22·9		
	Mean min.	15·8	12·2		7·7	4·9	5·0		6·6		

8. Longevity of the winged stage

The life of adults (in days) from the date of acquiring wings to the date of death at four constant temperatures is given in Table XXVII. The average durations of all the observations at each temperature are given in Table XXVIII.

TABLE XXVII

Longevity of adults at different constant temperatures

Temperature (°C.)	Ref. No.	Date of acquiring wings		Date of death		Adult life	
		Male	Female	Male	Female	Male	Female
40 . .	40 IA$_1$.	29th Jan. 1932.	29th Jan. 1932.	1st Mar. 1932.	26th Feb. 1932.	32	28
				14th Apl. 1932.			
	40 IA$_2$.	,,	,,	26th Feb. 1932.	29th Feb. 1932.	28	31
				29th Feb. 1932.	12th Mar. 1932.	31	43
	40 IA$_3$.	,,	,,	2nd Mar. 1932.	28th Feb. 1932.	33	30
				10th Mar. 1932.		41	
	40 IIA$_1$.	14th Mar. 1932.	14th Mar. 1932.	14th Apl. 1932.	22nd Apl. 1932.	27	39
	40 IIA$_2$.	,,	,,	4th Apl. 1932.	11th Apl. 1932.	21	28
				13th Apl. 1932.	14th Apl. 1932.	30	31
					Average life (days).	35	33
36 . .	C$_1$ . .	8th Dec. 1931.	8th Dec. 1931.	13th Jan. 1932.	31st Jan. 1932.	36	54
					31st Jan. 1932.		54
	IV$_1$ . .	15th Sept. 1931.	15th Sept. 1931.	...	22nd Oct. 1931.	...	37
	IV$_2$ . .	15th Sept. 1931.	14th Sept. 1931.	10th Dec. 1931.	26th Oct. 1931.	87	41
	III$_1$ . .	13th July 1931.	13th July 1931.	26th Aug. 1931.	11th Aug. 1931.	44	29
	III$_2$ . .	,,	,,	,,	14th Aug. 1931.	...	32
	III$_3$ . .	24th July 1931.	,,	30th Aug. 1931.	16th Aug. 1931.	37	34
	. .			30th Aug. 1931.		37	
	T$_2$ . .	14th May 1931.	14th May 1931.	29th June 1931.	7th June 1931.	46	24
				29th June 1931.	17th June 1931.	46	34
					30th June 1931.		47

TABLE XXVII—*contd.*

Longevity of adults at constant temperatures.

Temperature (°C.)	Ref. No.	Date of acquiring wings		Date of death		Adult life	
		Male	Female	Male	Female	Male	Female
	T_3 . .	18th May 1931.	18th May 1931.	11th June 1931.	25th June 1931.	24	38
				27th June 1931.	29th June 1931.	40	42
					30th June 1931.		43
	N_1 . .	10th Mar. 1931.	12th Mar. 1931.	14th Apl. 1931.	...	35	...
			13th Mar. 1931.		6th Apl. 1931.		35
					18th Apl. 1931.		36
	N_2 . .	17th Mar. 1931.	17th Mar. 1931.	20th Apl. 1931.	14th Apl. 1931.	34	28
	L_{60} . .	27th Jan. 1932.			21st Feb. 1932.	...	25
		24th Feb. 1932.	24th Feb. 1932.	9th Mar. 1932.	21st Mar. 1932.	14	26
					Average life (days).	39·7	36
30 . .	30 B . .	21st Jan. 1931.	10th Jan. 1931.	16th Mar. 1931.	23rd Mar. 1931.	54	72
	30 A . .	,,	,,	17th March. 1931.	17th Mar. 1931.	55	66
	29 C . .	10th Jan. 1931.	,,	8th Mar. 1931.	17th Mar. 1931.	57	66
	29 B . .	,,	,,	23rd Mar. 1931.	11th Feb. 1931.	72	60
	29 A . .	,,	,,	26th Mar. 1931.	8th Mar. 1931.	75	57
					Average life (days).	62·6	64
27 . .	...	18th Dec. 1930	...	12th Mar. 1931.	...	85	...

TABLE XXVIII

Longevity of adults at constant temperatures (Summary)

Temperature (°C.)	No. of observations	Average adult life (days)	
		Male	Female
40	16	35	33
36	30	39·7	36
30	10	62·6	64
27	1	. .	85

It will be notcied that as the temperature falls from 40° C. to 27° C., the duration of adult life increases.

A number of observations on the duration of adult life at room temperature from April to November, 1930, are given in Table XXIX. The average durations of all observations in different months are given in Table XXX. Adults dying within a week of their acquiring wings have been excluded from the record presented in these tables, since such deaths, most definitely, must have occurred as the results of abnormal causes.

TABLE XXIX

Longevity of adults kept at room temperature.

Cage No.	Sex	Date of acquiring wings	Date of death	Adult life (days)
N7 b3 .	Male	1st April 1931	18th May 1931.	47
	Female . . .	,,	22nd May 1931.	51
I_{22} . .	Males	4th Apl. 1931	17th June 1931.	74
			21st June 1931.	73
			13th July 1931.	100
	Female . . .	,,	2nd July 1931.	39
Nil .	Male	9th Apl. 1931	1st June 1931.	53
	Female . . .	5th Apl. 1931	19th May 1931.	44
I_9 . .	Males	18th April 1931.	28th May 1931.	40
			2nd June 1931.	45
I_8 . .	Male	28th April 1931.	30th May 1931.	32
	Female . . .	,,	15th June 1931.	48

TABLE XXIX—*contd.*

Cage No.	Sex	Date of acquiring wings	Date of death	Adult life (days)
I_9 . .	Females	29th April 1931.	8th June 1931.	40
			6th June 1931.	38
I_{12} . .	Male	30th April 1931.	30th May 1931.	30
			Average .	53·9
I_{11} . .	Male	2nd May 1931	23rd June 1931.	52
I_{10} . .	Male	5th May 1931	26th May 1931.	21
	Female . . .	,,	17th June 1931.	43
I_{13} . .	Male	,,	19th June 1931.	45
	Female . . .	,,	23rd June 1931.	49
I_{15} . .	Males	,,	9th June 1931	35
			1st July 1931.	57
I_{14} . .	Male	6th May 1931	9th July 1931	64
	Female . . .	,,	14th July 1931.	69
I_7 . .	Male	7th May 1931	21st June 1931.	45
	Female . . .	,,	15th June 1931.	39

TABLE XXIX—*contd.*

Cage No.	Sex	Date of acquiring wings	Date of death	Adult life (days)
I_{12}	Male	8th May 1931	26th June 1931.	4
	Females	,,	2nd June 1931.	2
			8th June 1931.	31
			9th June 1931.	32
			2nd Aug. 1931.	86
I_{11}	Male	10th May 1931.	18th June 1931.	39
R43d	Male	16th May 1931.	29th June 1931.	44
	Female	,,	26th June 1931.	41
II_6	Male	16th May 1931.	27th June 1931.	42
	Female	,,	3rd June 1931	18
I_{15}	Females	20th May 1931.	30th May 1931.	10
		22nd May 1931.	8th July 1931.	47
			Average	42·74
Q_2	Male	15th June 1931	27th July 1931	42
	Female	,,	8th Aug. 1931	54
Q_3	Male	,,	20th July 1931	35
	Female	,,	25th July 1931	40

TABLE XXIX—*contd.*

Cage No.	Sex	Date of acquiring wings	Date of death	Adult life (days)
Q_4	Male	15th June 1931	8th Aug. 1931	54
	Female	,,	3rd Aug. 1931	49
Q14(i)	Male	,,	8th July 1931	23
	Female	,,	24th July 1931	39
Q14(ii)	Male	,,	24th July 1931	39
	Female	,,	21st July 1931	36
Q15(i)	Female	,,	15th July 1931	30
Q15(ii)	Female	,,	15th July 1931	30
II_1	Male	24th June 1931	17th Aug. 1931	54
	Female	,,	18th Aug. 1931	55
II_2	Female	,,	15th July 1931	21
II_3	Male	,,	23rd July 1931	29
II_4	Male	,,	6th July 1931	12
II_3	Male	26th June 1931	15th July 1931	20
	Female	,,	22nd Sept. 1931	88
II_4	Males	26th to 29th June 1931	4th July 1931	5-8
	Females	,,	4th Aug. 1931	36-39
II_5	Males	26th June 1931	22nd Aug. 1931	57

Cage No.	Sex	Date of acquiring wings	Date of death	Adult life (days)
II_3	Male	27th June 1931	15th July 1931	18
	Female	,,	29th July 1931.	32
II_4	Male	,,	4th July 1931	7
	Female	,,	4th Aug. 1931	38
II_5	Male	,,	30th July 1931.	33
	Female	,,	16th Aug. 1931	50
			Average	35·9
II_4	Male	5th July 1931	29th July 1931	24
II_7	Male	12th July 1931	6th Sept. 1931	56
	Female	,,	30th Aug. 1931	49
Q16	Male	13th July 1931	1st Sept. 1931	50
Q1	Males	11th—15th July 1931	31st Aug. 1931	47-51
	Female	11th July 1931	11th Sept. 1931	62
II_2	Males	22nd July 1931	1st Aug. 1931	10
			4th Sept. 1931	44
	Female	,,	25th Aug. 1931	34
II_{11}	Male	,,	25th Aug. 1931	34

TABLE XXIX—*contd.*

Cage No.	Sex	Date of acquiring wings	Date of death	Adult life (days)
II_{13}	Male	24th July 1931	30th Aug. 1931	37
	Female	”	11th Sept. 1931	49
II_{14}	Male	”	30th Aug. 1931	37
	Female	”	2nd Sept. 1931	40
II_{15}	Male	”	26th Aug. 1931	33
	Female	”	9th Sept. 1931	47
	Female	”	31st Aug. 1931	38
			Average	40·61
II_{8}	Male	2nd-3rd Aug. 1931	8th Aug. 1931	5-6
	Female	”	11th Sept. 1931	39-40
II_{17}	Male	3rd-8th Aug. 1931	9th Sept. 1931	29-34
	Female	2nd-5th Aug. 1931	6th Sept. 1931	32-35
II_{18}	Male	22nd Aug. 1931	2nd Sept. 1931	11
	Female	”	27th Sept. 1931	36
			Average	26·7
39a	Female	16th Aug. to 6th Sept. 1930	13th April 1931	219-240

TABLE XXIX—*contd.*

Cage No.	Sex	Date of acquiring wings	Date of death	Adult life (days)
39b .	Male	16th Aug. to 6th Sept. 1930	19th April 1931	225-245
	Female . . .	,,	7th April 1931	213-234
			Average .	229·33
47a .	Male	2nd-7th Oct. 1930	25th April 1931	200-205
	Female . . .	,,	,,	200-205
47b .	Male	,,	30th April 1931	205-210
	Female . . .	,,	13th April 1931	188-193
48a .	Male	,,	26th April 1931	201-206
	Female . . .	,,	19th April 1931	194-199
35 . .	Male	17th Oct. 1930	18th April 1931	183
	Female . . .	,,	30th April 1931	195
8 . .	Male	18th Oct. 1930	4th May 1931	198
	Female . . .	,,	27th April 1931	192
13 . .	Male	,,	30th April 1931	195
	Female . . .	,,	2nd April 1931	167
18a .	Male	20th Oct. 1930.	3rd April 1931	166
	Female . . .	,,	10th April 1931	173
18b .	Female . .	,,	11th April 1931	174

TABLE XXIX—*contd.*

Cage No.	Sex	Date of acquiring wings	Date of death	Adult life (days)
49a	Male	27th-31st Oct. 1930.	26th Feb. 1931	118-122
	Female	,,	5th April 1931	156-160
50b	Male	,,	8th April 1931	159-163
	Female	,,	30th April 1931	181-185
51b	Male	,,	17th April 1931	168-172
	Female	,,	6th April 1931	157-161
53	Male	,,	11th April 1931	162-166
	Female	,,	6th April 1931	157-161
54	Female	,,	7th April 1931	158-162
			Average	178·4
40a	Male	16th Oct. to 24th Nov. 1930.	19th April 1931	147-186
	Female	,,	12th April 1931	140-179
40b	Male	,,	25th April 1931	153-192
	Female	,,	12th April 1931	140-179
41	Male	16th Oct. to 3rd Nov. 1930.	19th April 1931	168-186
	Female	,,	17th April 1931	166-184
46b	Male	,,	22nd April 1931	171-189
	Female	,,	14th April 1931	163-181
			Average	170·25

TABLE XXX

Average longevity of adults during different months at room temperature

Month in which wings acquired	No. of observations	Average adult life (days)
April	15	53·9
May	23	42·7
June	28	35·9
July	17	40·6
August	6	26·7
September	3	229·3
October	24	178·4
November	8	170·3

It will be observed that from April onwards as the season gets warmer the duration of the adult life decreases. It is minimum from June to August and begins to increase after this. Under laboratory conditions the tendency to over-winter begins to appear in adults acquiring wings in the end of August, while almost all the adults acquiring wings from September to November over-wintered.

9. Total life and number of broods in a year

As already mentioned, various views have been entertained regarding the number of broods of *Schistocerca gregaria* in a year, but all the investigators hold one thing in common, *i.e.*, *Schistocerca gregaria* undergoes a compulsory long diapause in the adult stage thus restricting its broods to only one or two per year. Vayssiere [1932], King [1922], Uvarov [1928] and Bodenheimer [1929] are of opinion that the Desert Locust has only one generation in the year with a long diapause in the adult stage. On the other hand Cotes [1891] Künckel [1905], Vosseler [1905] and Regnier, Lespes and Rungs [1931] are inclined to think that there are two generations in a year, the adults of the winter generation undergoing a long diapause. Ballard and others [1932] are of opinion that under favourable natural conditions there may be three broods in a year—a spring generation, a summer generation and an autumn generation.

Our observations definitely prove that there are normally two distinct broods in nature under Indian conditions. The over-wintered females begin laying eggs in February and die out by the end of May. In the second brood the oviposition starts in July and adults die off before November.

Experiments conducted at constant temperatures go to prove that there is no diapause in *Schistocerca gregaria* in any stage of its life-cycle and that the duration in various stages mainly depends upon external factors and particularly temperature. Thus, given suitable temperature (27°C.–40°C.) throughout the year, *Schistocerca gregaria* may have more than two broods.

The average total life and the number of broods which may be reared in the laboratory at different constant temperatures are given in Table XXXI.

TABLE XXXI

Average total life (days) and number of broods of Schistocerca gregaria *at different constant temperatures*

Temperature (°C.)	Egg stage	Larval stage	Adult stage	Total life	Pre-oviposition period	Duration of one brood	No. of broods in a year
40 .	11·0	20·7	34	65·7	14·3	46·0	7·9
36 .	12·0	21·2	37·8	71·0	17·6	50·8	7·2
30 .	16·0	30·9	63·3	110·2	24·2	71·1	5·1
27 .	20·0	45·4	85	150·4	32·0	97·4	3·7

It will be observed that it is not the total life of the insect which has been taken into consideration for calculating the number of broods in a year, but the duration of the egg stage, the larval stage and the pre-oviposition period put together give the duration of one brood. The cycle, therefore, is from egg to egg. Once oviposition has occurred, the life of the adult has no control on the life-cycle and its duration.

The number of broods at laboratory temperature.—As already pointed out the earliest eggs laid in the last week of February take three to four weeks to hatch, the hopper stage lasts for five to six weeks and the pre-oviposition period in early summer requires another two to three weeks; so that the adults of the first brood are usually ready to lay eggs in the 2nd and 3rd weeks of June. The second brood falling in the hot months completes the life cycle quicker. The adults may appear in the beginning of August and oviposition may commence after another two weeks. The temperature now begins to fall and the larvae of 3rd brood reach adult stage from the middle of October to middle of November. These adults over-winter and produce next generation in early spring. Thus, under laboratory conditions three broods of *Schistocerca gregaria* can be bred in a year. (For laboratory temperature record see Tables XVIII and XXV).

10. Summary.

The biology of *Schistocerca gregaria* has been studied at constant temperatures and general conclusions confirmed by a large number of observations at room temperature.

Pre-copulation and pre-oviposition period or, in other words, the sexual maturity of adults depends on temperature. It varies from 14·2 days at 40°C. to thirty-two days at 27°C. If, however, a temperature below 20°C. prevails for a long time, this period may be very much prolonged. This is why under natural conditions the adults of the over-wintered brood take six to seven months to commence oviposition. Under laboratory conditions a maximum number of eleven packets of eggs was obtained, each being laid at an interval of three days to three weeks depending on temperature.

The theoretical threshold of development of eggs lies at 17°-18°C. The incubation period varies from eighty-five days at 18·5°C. to a minimum of nine days at a temperature above 40°C. Eggs exposed to 46°C. for eight hours or more do not develop.

The larvae of *Schistocerca gregaria* cannot complete their development at 20°C. and below. The larval period is sixty-two to sixty-three days at 27°C., while it is only twenty days at temperatures between 36° and 40°C. The larvae are unable to moult at 46°C., which, therefore, represents the upper vital limit for this species.

The longevity of the adults is inversely proportional to the environmental temperature. At temperatures above 36°C. the adult life is about one month. At temperatures below 30°C., the adults may live for two to three months or even more.

Under natural conditions in the Punjab there are only two broods in a year. The adults of the over-wintered brood lay eggs from February to April, and die out by May, those of the summer brood lay eggs from July to September. Under favourable conditions of temperature, however, the locust can breed quicker and produce several broods in a year. These observations definitely prove that there is no diapause in *Schistocerca gregaria* in any stage of its development and the duration of various stages depends mainly upon environmental conditions of which temperature is by far the most important.

REFERENCES

Ballard, E., Mistakawi, Eff. A. M., and Zoheiry, Eff.M.S. (1932). *Tech. and Sci. Bull.* **110**. *Ministry Agric., Egypt.*

Bodenheimer, F. S. (1930). *Z. angew. Ent.* **15**, 1-123.

Bucher, H. (1918). D. *Monog. angew. Ent., Berlin* 3, 274 pp.

Cotes, E. C. (1891). *J. Bom. Nat. Hist. Soc.* **6**, 242-262.

King, H. H. (1922). *Sudan Notes & Rec., Khartoum* **5**, 54-56.

Künckel d'Herculais, J. P. A. (1893-1905). 'Invasions des Acridiens vulgo Sauterelles en Algerie. Alger', 2 vols.

Lespes, L. and Rungs, C. (1931). *C. R. Acad. Sci. Fr., Paris* 192, 1485-1487.

Parker, J. R. (1930). *Bull. Univ. Montana, Agric. Expt. Stn.* 223, 132.

Regnier, P. R. (1926). Les Acridiens ravageurs du Maroc. Dir. Gen. Agric. Maroc., Rabat, 24 pp.

Telenga, N. A. (1930). *Izv. Khorezm. S.—Kh. op. St.* (*Bull. Khorezm Agric. Expt. Stn.*), *No.* **6**, 27 pp. Moscow (In Russian).

Uvarov, B. P. (1928). "Locusts and grasshoppers: A hand-book for their study and control." London; 352 pp.

Vayssiere, P. (1932). *C R. Acad. Sci. Fr., Paris* **195**, *94-96.*

Vosseler. J. (1905). Die Wanderheuschrecken in Usambara in Jahre 1903/1904, zugleich ein Beitrag zu ihrer Biologie. *Ber. Ld.-u. Forstw. D. Ostafr.* 2: 291-347.

STUDIES ON *SCHISTOCERCA GREGARIA* FORSK.*

III. WHY LOCUSTS EAT WOOL

A study in the hydromania of Schistocerca gregaria

BY

M. AFZAL HUSAIN, M.A. (Cantab.), I.A.S.,

AND

C. B. MATHUR, M.Sc. (Luck.),

Locust Research Laboratory, the Punjab Agricultural College, Lyallpur

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CONTENTS

	Page
I. Introduction	263
II. Problem	264
III. Experiments and observations	264
IV. Discussion	266
V. Summary	267
References	267

I. Introduction

Locusts are notorious for their unappeasable hunger, and for a voracity rarely equalled elsewhere in the animal kingdom. Their dietary covers a very wide range of vegetation. There are exceedingly few cultivated plants that they would refuse to feed on and very few wild ones which they would not eat.† Nor do they confine their destructive activities to soft leaves and juicy green twigs. They are known to gnaw the hard bark of *babul* (*Acacia arabica*)

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*Studies on *Schistocerca gregaria* Forsk.

I. The micropyle in *Schistocerca gregaria* Forsk. and some other Acridiidae. *Ind. J. Agric. Sci.* **3**:639-645. 1933.

II. The biology of the desert locust with special relation to temperature. *Ind. J. Agric. Sci.* **6**:188-262. 1936.

† It is implied that the locusts are absolutely indiscriminate feeders. There are a few plants which they would refuse to eat. There are others which are eaten in case of extreme privation only.

trees till the wood is laid bare and the tree looks white from root to top. In the diary of a *Naib* of Bhag (Kalat, Baluchistan) a case is recorded from village Audro Qadir Bux (May 1924) where "a large number of hoppers having hatched out attacked wheat that had been reaped, heaped and blown". This appears rather extraordinary and without verification one is not prepared to accept this statement, but there is 'no telling', so out of the ordinary are these 'beasts'! They are known to nibble at window and door frames, make a meal of thatched roofs of houses and similar other materials and eat up their own disabled and dead comrades.* An unfortunate individual undergoing a moult sometimes becomes an object of a concerted attack by its comrades. Hoppers while just emerging from the soil are sometimes feasted upon by others which had hatched out earlier from the same egg cluster [Nikolsky, 1925]. Unconfirmed reports of their attack on human bodies are also on record.

Nikolsky [1925] recorded cases where the hoppers of Asiatic Locust (*Locusta migratoria* L.) ate off huge holes through felt tents. On their march through a village they gnawed through curtains and window blinds of dwellings and attacked bags and luggage.

Faure [1932] states: "Where grass is scarce the Brown Locusts (*Locustana paradilana* Walker) will no doubt eat almost anything and one hears of clothings, curtains and the like having been damaged during recent invasions."

The most extraordinary, and perhaps amusing, instance of all perversions is recorded by Nikolsky [1925], in regard to a swarm of hoppers which had appeared among a flock of sheep at night and by the morning had caused the flock to assume a closely shorn appearance, except for small patches of wool round the eyes.

II. PROBLEM

Why do locusts eat wool? Is it due to hunger? Or is it because of a 'hydromania'—an intense yearning for moisture?

Wool is a material which evidently can have practically no nutritive value for an insect, the digestive system of which is not adapted for such a diet. To discover the reason for this curious phenomenon of wool eating a series of experiments were conducted.

III. EXPERIMENTS AND OBSERVATIONS

(i) In a preliminary set of experiments some raw wool†, previously dried and weighed, was soaked in water and placed in a cage, alongside a fresh cabbage leaf, the usual food provided for the locusts bred in the laboratory. Two pairs of locust fliers were kept in this cage. Fresh leaves were supplied four times a day. After forty-eight hours the wool was removed from the cage, dried and weighed again. It showed no difference in weight. The leaves provided were eaten in all cases. Observations made in six repetitions of this experiment pointed to the conclusion that the Desert Locust has, at least, no preference for wool and will not eat it when green food is available.

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* The habit of eating their dead comrades is of practical importance. If the death be due to eating poison baits, the eater of dead body may itself die of poison. Granovsky [1926] has practically observed this.

† Raw wool was obtained fresh from local butchers.

(ii) In another set of experiments, the fliers were kept in a desiccator in which low humidity was maintained by means of concentrated sulphuric acid. They were kept without food for twenty-four hours at a temperature of 37°C. At the end of this period some dry wool was introduced into this desiccator. The fliers came to it but rejected it after a casual 'inspection'. After an hour some more wool soaked in water was introduced. This was eagerly eaten though the quantity eaten was not large. As dry wool is not acceptable to the hungry and thirsty locusts it is apparent that moisture in the soaked wool is the only factor which determines its acceptance.

It is also interesting to note here that a microscopic examination of the fæces of the locusts that had fed on wool showed wool fibres, which evidently had suffered no physical change in passing through the alimentary tract, except that the wool fibres had been cut into pieces by the action of the mandibles.

(iii) In the third set of experiments the fliers were starved under similar conditions as above, but at the end of a period of twenty-four hours a green cabbage leaf and some soaked wool were simultaneously introduced into the desiccator. The fliers took the shortest cut, made no selection and ate whichever of the two substances came handy. However, those that started with wool nibbled a small quantity and having satisfied, so to say, the bare, immediate, and pressing need for water turned away and having discovered the green leaf, ate it to their fill. This occurred in all the four desiccators and showed very clearly that the real need for nourishment was met only by eating the leaf, while soaked wool was eaten just to appease an irresistible craving for water.

(iv) In another experiment the fliers were again kept in a dry atmosphere, as before. They were provided with some dry bran, dried fig leaves and dried cabbage leaves. After forty hours it was discovered that the dried fig leaf had been slightly nibbled, but the dried cabbage leaf and bran had remained untouched. At this stage some soaked wool was introduced into the desiccator. This was eaten very readily, although, as before, the quantity eaten was not much.

It is safe to conclude once again that it was not hunger but thirst that drew locusts to wet wool. Thus it is really the desire for water that makes the locust eat such a 'non-edible' substance as wool. This hypothesis receives further support from the following experiment:

(v) Locusts were kept at 33°C. and at about ninety-eight per cent relative humidity, for forty-eight, sixty, seventy-two, eighty-four and ninety-six hours. No green food was provided. They were supplied with a weighed quantity of wool soaked in water. In all cases the wool was not eaten. Some of the fliers that were kept for eighty-four to ninety-six hours died without touching the moist wool.

The reason may be that since the percentage of humidity in these experiments was high*, the loss of water from the bodies of locusts was low, and there was no desire for water. Therefore, in the absence of thirst, the locust refused to eat moist wool, though this was greedily eaten by the locusts kept in an atmosphere with low humidity.

Nikolsky [1925] has quoted instances of the Asiatic Locust marching on a line upon which linen was spread for drying. They ate up the wet ones and left untouched those that had dried. This again is a proof for the hypothesis put forth. The record already mentioned of locusts eating wool from living sheep also finds a satisfactory explanation on the basis of this hypothesis. Obviously, the wool on their body must have been moist.

In this connection another observation of Nikolsky is of interest. He observed a band of hoppers of the Asiatic Locust marching in a desert tract. Having met a pond of water they concentrated on it and it was clearly seen that they were drinking water. In this laboratory also, sometimes, during hot dry days, the Desert Locust has been seen drinking water sprinkled on the soil of the rearing cages.

IV. Discussion

A certain amount of water in the tissues of an organism is absolutely necessary for its life. For the maintenance of this minimum the beasts of the desert have to make special efforts. A number of animals in the dry regions of the earth are known periodically to march across long stretches of sandy areas in quest of watering places. Birds of the desert go regularly to their watering places and bring back water for their young ones. Perhaps the most interesting contrivance for this is that of the Sand-grouse [Buxton, 1923]. They drink while standing in water with their breasts submerged and return home with the plumage on their breasts soaked in water. The young ones pass the feathers through their bills and keep on changing until the supply becomes exhausted.

Normally locusts get their supply of water through their food. When this is scarce and the loss of moisture from the body, in a warm and dry atmosphere, is excessive, a stage is reached, when, in order to live, the locust must obtain water from some other source. It is precisely under these conditions that locusts eat practically anything which can provide water.

In the deserts, during periods of drought when vegetation is parched, the vegetable-eating insects meet their demands for water by eating pieces of dry plants. In sandy deserts, while the days are excessively hot and dry, the nights are cool and the humidity is then very high. The diurnal range of humidity is very wide. Buxton [1924] has observed that often when the humidity during the day is as low as twenty per cent, during the night the air is nearly or quite saturated. Desiccated fragments of certain plants situated in an atmosphere containing eighty per cent humidity or more, absorb an amount of moisture equal to fifty to sixty per cent. of their own dry weight (Buxton). It is evidently on account of this moisture that a variety of apparently dry articles are eaten by the locust. In the case of wool on the body of the sheep, in addition to the small amount of hygroscopic moisture, it is likely, that a fair amount of free moisture should also have been existent.

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* Saturation deficiency below 1 mm.

It may be mentioned here that in the case of swarming hoppers the problem of water economy is heightened by their colour. It is well known that black absorbs more radiant heat than any other colour. Thus under the same climatic conditions a swarming (black) hopper will absorb more heat than a solitary (green) one and will therefore require more water for evaporation in order to keep down its temperature at the optimum, than a solitary (green) hopper would require. [In most animals the temperature of the body is brought down by evaporation of water from the body surface. Among insects this is done by evaporation through respiration (Buxton)]. Therefore, the swarming hoppers stand in greater need of moisture.

It can thus be safely concluded that sometimes even non-edible substances are eaten by locust to make up the amount of water required for its existence. A study of the water requirements of locust under different conditions is intimately connected with the problem of locust control by means of poison baits. A dry bait is entirely useless and the failure of baiting in certain places may be attributed to this fact. Locusts need water, particularly in a dry atmosphere and this is exactly the atmosphere in which the bait would dry very quickly. Thus baiting cannot be employed by mere rule of thumb. One must study the environmental conditions before a proper control through this method can be obtained.

V. SUMMARY

Non-edible substances, like wool, are eaten by the Desert Locust to obtain moisture, such substances are not eaten if they are dry.

Substances containing a large amount of hygroscopic moisture are also eaten.

The tendency is particularly marked if the atmosphere is dry.

REFERENCES

Buxton, P. A. (1923). "Animal life in Deserts": London.

————————(1924). *Proc. Roy. Soc. London B* **96**.

Cotes, E. C. (1891). *Nat. Hist. Soc.* **6**.

Faure, J. C. (1932). *Trans. Univ. College, Pretoria, Bull.* 4, Sept.

Granovsky, A. A. (1926). *Econ. Ent.* **19**. No. 2. Geneva, N. Y.

Nikolsly V. V. (1925). *Bull Dept. Appl. Ent.* 12 (*In Russian*).

NITROGEN RECUPERATION IN THE SOILS OF THE BOMBAY PRESIDENCY, PART IV

BY

D. L. SAHASRABUDDHE, M. Ag., M. Sc.,

Agricultural Chemist to Government of Bombay,

AND

V. S. ABHYANKAR, B. Ag.,

Assistant to the Agricultural Chemist

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CONTENTS

		Pages
I.	Introduction	268
II.	Nitrogen fluctuations in non-irrigated soils	276
III.	Nitrogen fluctuations in soils under irrigated conditions	281
IV.	Nitrogen fluctuations in soils which are irrigated and are under crop all the year round	288
V.	Nitrogen fluctuations in soils under heavy rainfall conditions	294
VI.	Discussion of results	298
VII.	Conclusions	311
	References	311
	Appendix	313

I. Introduction

Historical

The investigation of the nitrogen recuperation in the soils of the Bombay Presidency was started as long ago as 1923 and the first results were published as a memoir with the title " Nitrogen Recuperation in the Soils of the Bombay-Deccan, Part I" [Sahasrabuddhe and Daji, 1925]. The experiments were conducted in the laboratory on samples of the medium black soil of the Deccan, taken at the end of the hot weather, kept dry and then exposed to varying conditions. The results showed that a good deal of nitrogen fixation takes place in the trap soils when they are moistened and kept at suitable temperatures. Further work on this subject was published in this *Journal* as "Nitrogen Recuperation in the Soils of the Bombay Presidency, Part II" [Sahasrabuddhe and Ghatikar, 1931]. For the investigation published in this paper, typical soils of the Bombay Presidency were obtained and the effects of the additions of lime, phosphatic substances, organic matter and alkali salts were studied. The results proved that at least under the controlled conditions of the laboratory, the addition of lime, phosphatic substances and organic matter improved the nitrogen recuperation of such soils as are not originally rich in these ingredients.

It remained, however, to be seen whether any recuperation takes place actually under field conditions. This investigation was undertaken soon after the publication of Part II and the results were published in this *Journal* [Sahasrabuddhe and Kanitkar, 1932]. Those results show that definite recuperation of nitrogen takes place in the soils under field conditions in the dry-farming tracts. Addition of organic matter increases the recuperative power of the soil. The quantities of nitrates also fluctuate between certain limits.

Since the publication of Part III, further work on the fluctuation of the nitrogen contents of the soil has been done by other investigators both in India and in other countries.

Prescott and Piper [1930] find that the activity of nitrification is greatest in surface layers which are cultivated, during the process of fallowing. There is evidence that the high nitrate accumulation is in late spring in spite of rapidly falling of moisture contents, because this is associated with the higher temperatures prevailing at these periods. Nitrate accumulation occurred rapidly with dry soil although more slowly than under the optimum condition (17 per cent moisture).

Penman and Rountree [1932] found that there was no appreciable interference with nitrate accumulation in cropped soils during the early life of the crop. At later stages comparatively very poor capacity for accumulating nitrate was observed in the cropped soils. This led to a disadvantage, in the case of cropped soil as compared with bare soil at harvest time.

The important results obtained by Bartholomew [1932] show that the accumulations of nitrates in the uncropped soils has an important practical significance. It shows very forcibly the necessity of keeping the ground covered with some kind of crop even though it is only weeds. The cover crops prevent loss of large quantities of available nitrogen and in addition add considerable active organic matter to the soil when ploughed in.

Nitrification processes take place at a minimum soil temperature of 40°F. if the soil conditions are favourable. Consequently, after crops have stopped growing, nitrification takes place and nitrates may accumulate in the soil before cold weather sets in.

Rheinwald [1933] in his paper on "Nitrate concentration of the soil solution and factors determining it," states that high temperature and moderate rainfall are important factors in the production of high nitrates in the soil solution. Heavy rains may seriously deplete the soil solution in the surface layer of nitrates and *vice versa.* Cropping tends to minimise variation in nitrates.

Desai [1933] in his experiments on "The influence of green manure and organic residues on nitrogen fixation in soils" found that fixation of nitrogen definitely takes place when green manure, straw or any other organic material is added to the soil under favourable conditions of temperature and moisture. Whether the crop is leguminous or non-leguminous the total nitrogen of the soil is brought up to the same level, because, although the leguminous plants are much richer in nitrogen at the time of addition to the soil, the subsequent nitrogen fixation in case of non-leguminous crop is much greater. The aeration of soil proved to be the main factor responsible for nitrogen fixation.

Garlach [1934] tried experiments on nitrogen fixation on artificially prepared soil by mixing sand, Kaolin, ground marble and the various salts with a small quantity of soil in suspension. From the results obtained by him it appears doubtful to him whether any free nitrogen fixation takes place in soils which are humus-free or which contain only small amount of organic matter. Such nitrogen fixation takes place in soils to which dextrose has been added as a source of energy for bacteria.

Vandecaveye and Villanueva [1934] found that "the quantities of nitrogen fixed during the course of the experiment varied with the organic matter content of the soils. Nitrogen fixation was greatly stimulated in three of the four soil samples which had received large amounts of carbonaceous organic residue."

Wilshaw [1934] observes that his experiments show that the total nitrogen content of the Malayan soil is subject to fluctuations which are too high to be accounted for by loss as soluble humate. He further says that one is forced to the conclusion that the enormous losses are mainly in the form of gaseous nitrogen. To counteract these losses, large recoveries are taking place producing the fluctuations observed. This can only mean that rapid fixation is occurring at certain periods.

Sreenivasan and Subrahmanyan [1934] state that it may be noted that there was considerable fluctuation in nitrogen similar to those recorded by some previous workers. On the other hand, the observations on the parallel plots show absolutely no relation to changes in season. The quantity of nitrates present at any time shows no relation to either season or treatment. They further state that although it is desirable to study changes in the different soils under conditions actually obtaining in field practice, there are yet serious inherent defects due to soil heterogeneity, etc.

The plan of work

The experiments in connection with recuperation of nitrogen under field conditions published in Part III, were carried out on soils which were brought under cultivation only a few years before the experiments were started. They were virgin soils up to 1924, occupied by scrub jungle and *babul* shrubs. There *juar* was taken as a *rabi* crop.

The present investigation was started to find out what fluctuations in soil nitrogen take place under other conditions of climate and soil treatment, especially the fluctuations of nitrogen in soils under irrigation and under heavy rainfall.

The experiments were conducted at three places—(1) Poona, (2) Belgaum and (3) Karjat. Each place has its own peculiar climatic conditions and soil treatments.

In Poona there were two sets of experimental plots, *viz.* one set of plots for *kharif* (rainy season) *juar* and the other set for turmeric under irrigation.

For the *juar* crop a small area was divided into two adjacent plots measuring 55 ft. × 20 ft. each. In one of them the crop was sown and the other was left uncropped but underwent the same cultural operations as the cropped plot.

Another area was selected for the irrigated crop in order to study the nitrogen fluctuations under conditions of irrigation. This was divided into two equal adjacent plots measuring 110 ft. × 10 ft. each. Turmeric was sown on the cropped plot and the adjacent uncropped plot received the same manure, irrigation and other operations as the cropped plot.

The experiments at Belgaum were conducted on a soil the constituents of which are derived from both trap and laterite rocks. The soil differs much from that of Poona. The climatic conditions also differ. The peculiarity of the tract is that three crops are taken in one year. Here an area was divided into three adjacent plots measuring 33 ft. × 33 ft. each. The first one was cropped throughout, the second was uncropped throughout but received all cultural operations including manuring and irrigation, while the third was left uncropped and received all cultural operations including irrigation but did not receive any manure.

At Karjat the soil is derived from trap. The tract received heavy rainfall from June to October. Rice is the crop taken from June to the middle of November. A suitable piece of land was divided into two adjacent plots measuring 33 ft. × 33 ft. each of which one was cropped and the other uncropped.

It will be noticed that in each case it was a single-plot experiment. As it was not possible to do the experiment in replicated plots, the difference between the individual figures as distinct from the general trend may be taken with reserve.

Chemical and mechanical analyses

TABLE I

Chemical analysis

	Poona *juar* plot	Poona turmeric plot	Belgaum laterite plot	Karjat trap soil plot
	On fine air-dry matter			
	Per cent	Per cent	Per cent	Per cent
Moisture	7·53	6·54	3·18	5·37
Loss on ignition	7·45	8·00	11·02	7·17
Sand (acid-insoluble)	62·46	65·47	49·61	61·86
Iron (Fe_2O_3)	6·49	6·34	17·58	11·40
Alumina (Al_2O_3)	6·57	5·72	16·64	11·26
Lime (CaO)	6·17	4·50	1·05	0·92
Magnesia (MgO)	2·00	1·82	0·98	2·36
Potash (K_2O)	0·36	0·36	0·55	0·22
Phosphoric acid (P_2O_5)	0·054	0·06	0·36	0·11
Organic matter (direct determination)	1·53	2·16	4·44	1·81
Total water-soluble salts	0·044	0·13	0·14	0·035
	Grams			
The maximum water-holding capacity of soil showed that 100 grams of oven-dry soil could take up given grams of water	78·32	71·29	75·91	67·30

TABLE II

Mechanical analysis

(By International Soda Pipette method. The soil was passed through one mm. sieve)

	Poona *juar* plot soil	Poona turmeric plot soil	Belgaum laterite plot soil	Karjat trap soil
	On fine air-dry matter			
	Per cent	Per cent	Per cent	Per cent
Moisture	7·53	6·54	3·18	5·37
Coarse sand	12·07	11·25	11·22	4·53
Fine sand	27·88	30·65	14·32	24·99
Silt	25·05	20·30	18·60	30·42
Clay	24·99	25·17	47·24	27·77

pH values

pH values for all the soil samples were determined by a potentiometer with a quinhydrone electrode.

Method of taking samples

Samples were taken by randomisation. From each plot twelve samples of surface soil of six in. depth were taken and thoroughly mixed up and a composite sample was taken, dried at 60° C. to prevent changes and then brought to Poona. Soil sample for moisture was taken separately. The randomised spots from which the samples were taken were distributed fairly evenly over the whole plot as will be seen from the detailed description later on.

The sampling error

There is a likelihood of error in collecting samples even though these are taken by randomisation. In order to find out the limits of this error, soil samples were collected from uncropped *juar* plot. Twelve samples were taken each time by randomisation and this was repeated six times on one and the same day. This gave six composite samples, each containing twelve samples as usual. The figures for total nitrogen were as follows :—

Table III

Total nitrogen in mgs. per 100 grms. of oven-dry fine soil

No. of composite sample of soil	Total nitrogen
	(Mgs.)
1	44·52
2	44·05
3	44·09
4	43·93
5	44·36
6	44·02

The standard deviation of these comes to 0·228. This is very small indicating that the method of collecting samples is satisfactory and the differences in the nitrogen contents of the samples need not be put down as due to error in sampling.

Soil temperatures were taken at 5 P. M. on the days on which samples were taken.

Methods of analysis

Total nitrogen.—Twenty grams of soil passed through one-mm. sieve, was taken in a Kjeldhal flask. The soil was moistened with distilled water and 50 c. c. of salicylic-sulphuric acid (one grm. in 30 c. c. of sulphuric acid) was added to it and kept overnight. Next day five grams of sodium thiosulphate and two to four grams of potassium sulphate were added. To this mixture 20 c.c. of salicylic-sulphuric acid were added again. It was digested as usual and distilled. The distillate was collected in 0·05 N sulphuric acid and then titrated against 0·05 N caustic potash. Indicator used was alizarine sodium sulphate, which gives a sharp change.

Ammoniacal and nitrate nitrogen

One hundred grams of soil, passed through one-mm. sieve was shaken for half an hour with 150 c.c. of normal sodium chloride, filtered through Buchner funnel and then leached with 350 c. c. of normal sodium chloride solution. The whole filtrate was transferred to a distilling flask. Three grams of magnesium oxide was added and distilled in 0·02 N sulphuric acid. The distillation continued till the distillate collected was 175 c. c.

To this flask three grams of magnesium oxide were again added with three grams of powdered Devarda's alloy and distilled in 0·02 N sulphuric acid till the distillate collected was 175 c.c. Both these distillates were titrated against 0·02 N caustic potash separately with alizarine sodium sulphate as an indicator.

Special precautions taken in analysing the samples

(*a*) Investigators often take five to ten grams of soil sample for nitrogen determination. Twenty grams of soil were taken in this case to minimise errors in the final figures which increase by multiplication.

(*b*) 0·05 *N* sulphuric acid was used for total nitrogen.

(*c*) 0·02 *N* sulphuric acid was used for nitrate nitrogen estimation [Crowther and Mirachandani, 1931] to make titration as accurate as possible.

(*d*) Blank determinations were done and corrections made accordingly.

(*e*) Glass-distilled water was used all through.

All these precautions were taken to minimise the working error as much as possible.

Working error

Whatever the precautions one may take, there is sure to be some working error in the case of soil nitrogen which is present in small quantities. It is essential that working error is determined to get an idea of the extent of real fluctuation after making necessary allowance for all sorts of errors. Soon after the work was started, a soil sample was collected by randomisation of the spots, etc., on a plot at Karjat. This composite sample was divided into eight parts and soil from each of these was analysed for total nitrogen, ammoniacal nitrogen and nitric nitrogen. The figures obtained were as follows :—

TABLE IV

Milligrams of nitrogen in 100 grms. of oven-dry soil

Serial No.	Total nitrogen	Ammoniacal nitrogen	Nitric nitrogen
	(Mgs.)	(Mgs.)	(Mgs.)
1	77·52	0·64	0·14
2	77·52	0·66	0·14
3	78·38	0·64	0·14
4	77·98	0·68	0·16
5	77·75	0·64	0·16
6	77·75	0·68	0·14
7	78·38	0·68	0·12
8	78·18	0·64	0·12

The standard deviation for total nitrogen comes to 0·3527. Any difference which is more than three times the standard deviation, *i.e.* 0·3527 × 3 = 1·0581, is significant. Similarly for ammoniacal nitrogen any difference beyond 0·054 and for nitric nitrogen any difference beyond 0·045 will be significant.

Climatic data

Records of climatic data for all the stations at which experiments were carried on are given in the Appendix.

II. NITROGEN FLUCTUATIONS IN NON-IRRIGATED SOILS

The field experiments on nitrogen recuperation given in Part III (1932) were laid out at Manjri on a soil which was newly brought under cultivation, which was rich in nitrogen (0·073 per cent) and which received agricultural operations for *rabi juar*. For the purposes of this investigation another set of conditions was taken. The land selected was under cultivation for years, and contained comparatively a small proportion of nitrogen (0·041 per cent). It was without manure for years and was treated for a *kharif* crop of *juar*. The area was taken on the Poona Agricultural College Farm which was divided into two adjacent plots measuring 55 ft. × 20 ft. each. Both of these received the same operations from beginning to end, with the difference that one of them was cropped and other was not cropped.

TABLE V

Operations	Date
Ploughing by C. T2 plough 7 in. to 8 in. deep .	18th March 1933
Discing by a disc harrow	22nd March 1933
Discing by a disc harrow	2nd May 1933
Harrowing by a blade harrow	3rd May 1933
Harrowing by a blade harrow	20th June 1933
Sowing by a country drill 12 in. apart . . .	30th June 1933
Harvesting	6th December 1933

The previous crops on these plots were maize (*kharif*) and gram (*rabi*) in 1931-32 and *nilwa* (*kharif*) in 1932-33.

The depth of the soil was about two feet. The first samples of soils in connection with determination of nitrogen fluctuations in these plots were taken on the 30th of June and the subsequent samples were taken at the end of every month.

All the analytical figures are expressed on fine oven-dry soil. Every month twelve samples from each plot were taken by randomisation of spots and a composite sample of these was dried at 60° C. and taken to the laboratory. The accompanying chart (Fig. 1) will give an idea as to how the twelve spots for soil samples were distributed. Spots are shown for the month of December 1933 only as these are enough to show the distribution without causing confusion.

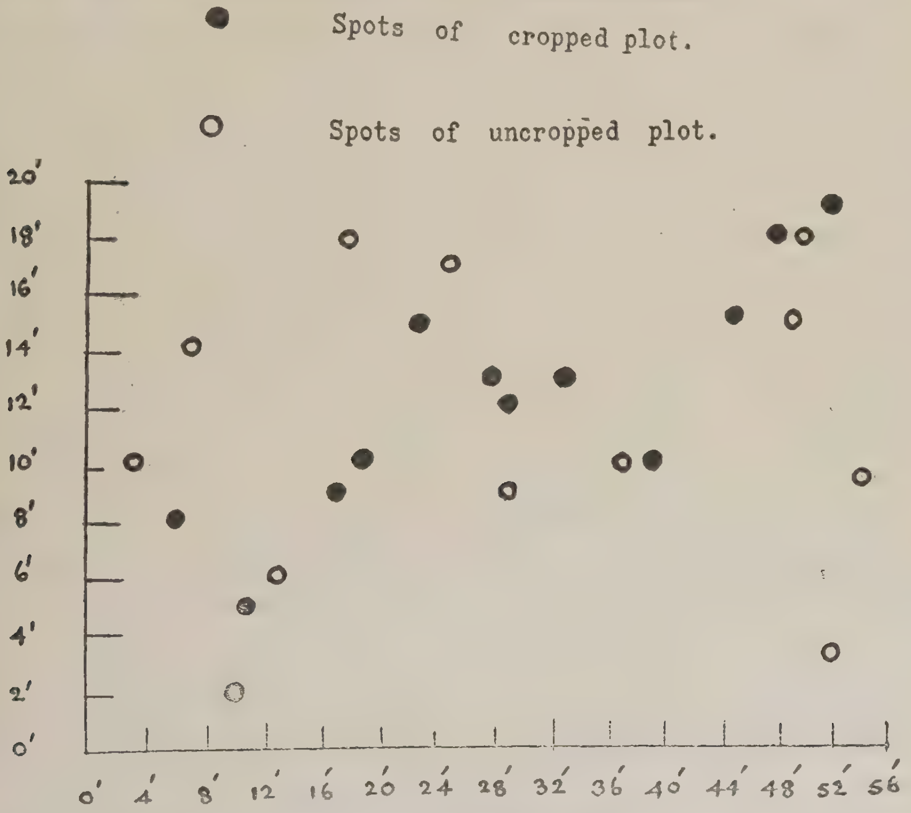

Fig. 1. Distribution of the twelve spots of soil samples at Poona '*juar* plot' for December 1933.

(*1*) *Nitrogen fluctuations on a plot on which* kharif juar *was grown.*

Total nitrogen and nitric nitrogen were determined from June 1933 to July 1934 to get one overlapping month. The following table gives total and nitric nitrogen along with the moisture contents of the soil. Soil temperatures were always taken at 5 P. M. on the days on which samples were collected. These temperatures may be useful as they are of the soil itself. It is quite possible that the nitrogen fluctuation may be affected by the minimum and the maximum temperatures of the whol

TABLE VI

Soil temperature, moisture, pH values, total and nitric nitrogen in mgs. per 100 grms. of oven-dry fine soil

Time	Soil temperature	Soil moisture	pH value	Total nitrogen	Nitric nitrogen
1933					
Last week of—	°C.	Per cent		Mgs.	
June	..	33·83	8·30	51·07	0·21
July	..	41·05	8·39	43·38	0·10
August . . .	..	31·01	8·33	48·52	0·11
September . . .	33·6	31·86	8·23	56·67	0·20
October . . .	28·1	26·54	8·20	49·22	0·58
November . . .	29·17	29·63	8·37	47·82	0·45
December . . .	29·6	26·86	8·19	54·04	0·64
1934					
January . . .	31·8	21·52	8·32	47·15	1·49
February . . .	32·0	17·80	8·29	53·81	0·96
March . . .	36·0	12·02	8·27	54·44	0·31
April	37·9	8·86	8·34	52·91	0·15
May	39·3	8·71	8·14	52·37	0·29
June	26·0	29·45	8·38	50·92	0·36

It has already been shown that any difference which is more than 1·057 milligrams is significant. There is therefore no significant difference between the total nitrogen of February and March and also between that of April and May. But the fluctuations in total nitrogen for other months are significant. There is a sudden fall from 51·07 to 43·38 milligrams per 100 grams of oven-dry fine soil between June and July samples. The July sample was collected on the 28th of

July. Just previous to that date there was a rainfall of 4·62 inches (Appendix A). This must have washed away nitrogen to a certain extent and hence the lower figures for July. High figures for nitrogen are obtained in September, December and March. In September, although the crop is growing, there is a high proportion of water (not too much as in July) in the soil and the temprature also is high. This explains why the nitrogen contents are high in September. From November onwards the nitrogen contents rise although the water-contents and the temperatures slowly go down. This is because the crop which feeds on the nitrogen is removed. In January the nitrogen figure is low because the minimum temperature of that month is as low as 8 to 10°C. From February onwards, although the temperature rises, the moisture goes down and hence the two factors working against each other minimise fluctuations. The nitrogen figures for June 1933 and June 1934 do not differ from each other significantly. This clearly proves once again as shown by Sahasrabuddhe and Kanitkar [1932] that the total nitrogen of a soil is not constant but goes on increasing and decreasing forming a sort of an annual cycle. When a crop like *juar* is grown without manure but with all the necessary cultivation, the soil is able to recuperate all the nitrogen and this cycle may go on year after year under the climatic conditions of the Bombay-Deccan. The maximum fluctuation is from 43·38 to 56·67 milligrams per 100 grms. of oven-dry fine soil, *i.e.* a maximum fluctuation of 30·6 per cent. This does not mean that the soil becomes richer in nitrogen by 30·6 per cent at the end of the year but it shows the range of rise and fall and how the nitrogen contents of the soil are kept up from year to year.

The pH values of the cropped plot vary only but slightly, ranging from 8·16 to 8·39. The values are slightly lower in the months of September, October, December and May than in other months.

The pH values in the uncropped plot range from 8·16 to 8·53, showing a little greater range than in the cropped plot. The pH values for July, September, October, January and February are somewhat lower than for other months.

Nitric nitrogen as given in Table VI above shows a great fall from June to July on account of the heavy rainfall just before July sample was taken. After that there is a steady rise till January. In December, January and February the nitric nitrogen is high and then goes down. It would have fallen in June 1934 if the rains at that time had been as heavy as in June 1933.

(2) *Nitrogen fluctuations on an uncropped plot adjacent to the* juar *plot.*

As already stated, the uncropped plot received all the cultivation treatments as the plot under *juar* and any differences that may be observed are due to the absence of the crop. Table VII gives all the important figures.

TABLE VII

Soil temperature, moisture, pH values, total and nitric nitrogen in mgs. per 100 grms. of oven-dry fine soil

Time	Soil temperature	Soil moisture	pH value	Total nitrogen	Nitric nitrogen
1933					
Last week of—	°C.	Per cent.		Mgs.	
June	..	33·97	8·30	51·07	0·21
July	..	43·42	8·18	46·38	0·31
August	..	33·12	8·37	44·01	0·34
September	33·5	32·59	8·31	43·84	0·28
October	31·8	24·54	8·16	44·58	0·46
November	30·17	29·75	8·18	46·20	0·43
December	28·80	27·10	8·25	49·13	0·69
1934					
January	32·40	20·68	8·22	46·54	0·78
February	32·25	15·90	8·23	44·39	1·00
March	36·20	12·30	8·49	41·27	0·51
April	38·20	8·90	8·48	42·59	0·34
May	38·70	9·20	8·53	41·22	0·35
June	26·00	33·34	8·53	42·82	0·41

The total nitrogen contents for August, September and October are not significantly different. All the other figures show significant fluctuations. There is a fall from June to September and a rise from September to December. Then again there is a fall with a small fluctuation till May, and then a small rise. The highest figure is 51·07 mgs. in June and the lowest in May 41·22 mgs. Therefore the maximum fluctuation is 23·1 per cent.

The nitric nitrogen is high in December, January and and February as on the cropped plot. Except in the months of October, November and January, the nitric nitrogen is higher in the uncropped than in the cropped plot.

The nitrogen in the cropped and the uncropped plot was the same to start with, as the previous treatment of the plot was exactly the same. Later on the total nitrogen is lower in the uncropped plot than in the cropped plot throughout the period of the experiment. At the end of the year the uncropped plot is below the cropped plot in nitrogen. When the crop is removed the roots and fallen leaves get incorporated into the soil and thus add to the organic matter, but on the uncropped cultivated land nothing of that sort happens and hence the lowering of nitrogen in the uncropped plot. This confirms the results obtained by Sahasrabuddhe and Ghatikar [1931], Sahasrabuddhe and Kanitkar [1932], and also proved by Desai [1933], Penman and Rountree [1932], Vandecaveye and Villanueva [1934] and others that organic matter helps fixation of nitrogen. This means that if a land is cultivated it should be cropped. If it is left uncropped its nitrogen content is lowered.

III. NITROGEN FLUCTUATIONS IN SOILS UNDER IRRIGATED CONDITIONS

In Part III [Sahasrabuddhe and Kanitkar, 1932] and in section II of this paper experimental results are discussed for nitrogen fluctuations in non-irrigated soils. But there are lands on which irrigated crops are grown and it is therefore important to ascertain what sort of nitrogen fluctuations take place under irri ation conditions. A suitable plot was taken on the Poona Agricultural College Farm and divided into two plots each measuring 110 ft. × 10 ft. side by side with each other. A crop of turmeric was put on, one with the usual cultivation operations, manuring and irrigation, and the other plot was without a crop but received cultivation, manuring and irrigation as the first one. The weeds that came up were removed along with the weeding of the cropped plot. Nitrogen determinations were done from month to month by obtaining a composite sample from the twelve spots taken by randomisation. The distribution of the spots is shown in the accompanying chart (Fig. 2) for the month of April 1934 only. Beside these monthly samples taken for thirteen months other samples were taken from both, the cropped and the uncropped area from two depths 0 in. to 6 in. and 6 in. to 9 in. to see the difference in fluctuations of nitrogen in the two layers. All these determinations were carried out with the idea of getting the exact effect of irrigation.

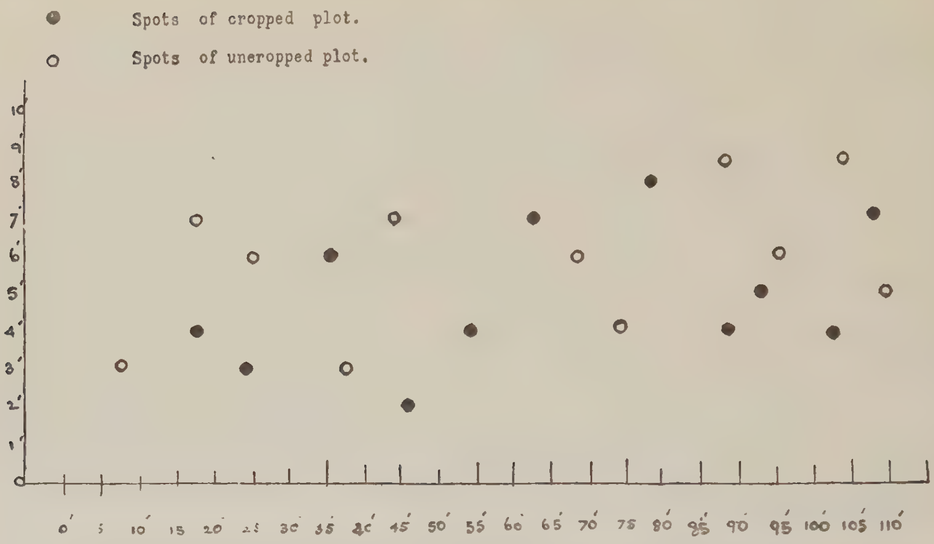

Fig. 2. Showing the distribution of the twelve spots of soil samples at Poona 'turmeric plot' for April 1934.

The soil of these plots is about a foot to one and a half foot deep. It is richer in organic matter and nitrogen than the soil for *juar* plots dealt with in the previous section.

As the irrigated plots were on the College Farm, the rainfall, temperature and humidity tables for these plots are the same as those for *juar* plots given in Appendix A. The cultivation and other operations including irrigation are given along with their dates in Table VIII.

TABLE VIII

Operations	Date
Ploughing by C. T. plough 7 in. to 8 in. deep . .	23rd March 1933
Manuring with farmyard manure at 20 cart-loads per acre. Discing by a harrow	24th May 1933
Preparing broad ridges 5 ft. apart by Victory plough.	25th May 1933
Planting sets at 12 in. × 12 in. apart	26th May 1933
Watering	27th May 1933
Weeding	21st June 1933
Watering	11th July 1933
Weeding by hand	18th August 1933
Top dressing at the rate of 62 lbs. nitrogen per acre, half in the form of sulphate of ammonia and half in the form of groundnut cake powder	7th October 1933
Watering approximately at intervals of ten days from .	28th October 1933 to 20th February 1934
Weeding by hand	18th November 1933
Weeding by hand	1st December 1933
Harvesting	12th March 1934

Operations during 1934

Ploughing with C. T. 2 plough	23rd April 1934
Clod crushing with Norwaygian harrow . . .	24th May 1934

On the turmeric plots the previous crops were maize (*kharif*) and gram (*rabi*) in 1931-32 and *shalu juar* (*rabi*) in 1932-33.

Table IX gives the pH values, the moisture-contents and total nitrogens of the cropped and uncropped irrigated plots; the temperatures of the soils of the two plots at the time of taking samples did not vary beyond 1°C. and hence the temperatures of the cropped plot only are given.

TABLE IX

Soil temperature, moisture, pH values, total nitrogen in mgs. per 100 grams of oven-dry fine soil

Time	Soil temperature	Cropped			Uncropped		
		Soil Moisture	pH value	Total nitrogen	Soil moisture	pH value	Total nitrogen
1933 Last week of—	°C.	Per cent		(Mgs.)	Per cent		(Mgs.)
June . . .	..	26·00	8·19	87·25	27·11	8·19	87·25
July . . .	..	25·92	8·48	75·11	27·67	8·28	82·65
August . .	..	22·11	8·30	70·59	20·87	8·42	80·63
September . .	..	21·79	8·35	72·07	21·63	8·32	76·34
October . .	..	16·33	8·30	77·84	16·67	8·32	76·91
November . .	27·0	21·84	8·27	76·33	24·98	8·17	77·15
December . .	28·5	21·27	8·30	84·03	22·03	8·42	83·02
1934 January . .	28·1	19·40	8·43	77·79	17·85	8·42	83·66
February . .	30·7	19·89	8·44	73·73	20·15	8·36	93·51
March . .	37·4	5·82	8·42	71·72	6·43	8·34	90·15
April . . .	38·0	5·53	8·28	82·20	6·47	8·49	78·96
May . . .	39·8	5·20	8·37	75·27	6·37	8·40	69·11
June . . .	28·6	25·72	8·45	75·69	24·18	8·45	73·24

The moisture in the uncropped plot in most cases is higher than in the cropped plot both during the rains and after.

In the cropped plot the fluctuation from May 1934 to June 1934 is not significant but all other fluctuations are significant. In May 1933 the plots received organic matter in the form of farmyard manure and there was rain in May and June. The soil sample for June 1933 therefore shows a high nitrogen figure. It goes down rather rapidly in July on account of the heavy rainfall (4·66 inches) just before the soil sample was taken. There is a further fall in August, a steady rise till December and a fall till March. When the crop is harvested in March, there is a rise in nitrogen contents in April on account of the removal of the crop. A fall soon starts as the soil contains but very little moisture. The sample of June 1934 was expected to come up to the level of the sample of June 1933 but the conditions were unfavourable.

In 1933, after the addition of the farmyard manure in May, there was good rainfall both in May and June. In 1934, however, there was no rain in May and farmyard manure was added as late as 15th June.

In the uncropped plot there is no significant difference between the total nitrogen figures for September and October and between the figures for October and November. The same is the case between the figures for December and January. All other fluctuations are significant. The nitrogen decreases from June to September. It remains at a low level during September, October and November and goes on increasing till February. From March onwards the irrigation is stopped, the soil moisture goes down very much and the nitrogen naturally decreases, falling to its minimum in May.

The difference between the irrigated cropped and irrigated uncropped plots is that the nitrogen is low in the cropped plot during the period the crop is growing, but when the crop is harvested the cropped plot shows more nitrogen than the uncropped one. After the crop is removed the organic matter in the form of roots, etc., which is left behind in the cropped plot, perhaps helps nitrogen fixation.

The maximum fluctuation of total nitrogen in the cropped plot is from 70·50 to 87·25 mgs. *i.e.* 23·6 per cent. In the uncropped plot it is from 69·11 to 93·51 mgs. *i.e.* 35·3 per cent.

The addition of 62 lbs. of nitrogen per acre as manure on the 7th of October makes but little difference, as when the quantity added is distributed over six inch acre, it comes to about 3 mgs. per 100 grms. of soil for October sample. But the variations from month to month are more than 3 mgs. before October and even after October.

There are slight of fluctuations in the pH values but there is no definite change in any direction in the cropped or in the uncropped plot.

The nitric nitrogen of the two plots under irrigation is given below :—

TABLE X

Nitric nitrogen in mgs. per 100 grams of oven-dry soil

Time	Cropped	Uncropped
1933		
Last week of—	(Mgs.)	(Mgs.)
June	0·43	0·43
July	0·49	0·33
August	0·21	0·27
September	1·10	0·81
October	2·23	1·13
November	1·34	3·51
December	2·63	3·91
1934		
January	2·29	3·62
February	2·17	2·83
March	1·72	4·37
April	1·86	2·29
May	1·40	1·58
June	2·32	3·46

Nitric nitrogen goes down till August. It then rises giving the highest figure in December for the cropped and the uncropped although there is another higher figure in the uncropped in March. The nitric nitrogen is less in the cropped than in the uncropped plot in most of the months.

The nitric nitrogen in June 1934 is much higher than that in June 1933 in both the cropped and the uncropped plots. This is perhaps because in the year 1933 there was a rainfall of 11·41 inches in May and June before the sample was taken and hence the nitrates were washed away. In May and June 1934, however, the rainfall before the soil sample was taken amounted only to 4·18 inches distributed all over the month and the nitrates were not washed away as in June 1933. When the July rains came, the total rainfall for May, June and July of 1934 went up to 8·31 inches. Nitrates got washed and the July figures for the nitrates in the soil came down as shown below :—

TABLE XI.

Nitric nitrogen in mgs. per 100 grms. of oven-dry fine soil

Month	Rainfall before the sample	Cropped plot	Uncropped plot
	Inches	(Mgs.)	(Mgs.)
May and June 1933	11·41	0·43	0·43
May and June 1934	4·18	2·32	3·46
May, June and July 1934	8·31	0·66	0·56

(2) *Difference in the nitrogen fluctuations of the upper six inches and the lower three inches of soil*

The irrigation water was analysed from time to time but it did not give any nitrogen, and so the figures for nitrogen were not in any way affected by irrigation waters. In determining fluctuations in nitrogen contents only the upper six inches of soil were used. It was, however, considered necessary to ascertain whether the nitrogen fluctuations in the lower three inches have the same trend as the upper six inches and whether the lower three inches contain more total nitrogen than the upper six inches. This is very important because if the tendency is to concentrate nitrogen in the lower layer, to study the fluctuations merely in the upper six inches may not give a complete idea of the variation taking place, especially on irrigated land where the tendency to wash down constituents is likely to be more than on unirrigated land.

In order to ascertain this, on certain occasions, samples of soils from the upper six inches and also those of 6-in. to 9-in. just below the upper samples, were taken by the usual method of randomisationa and preparing composite samples. This set was done quite independently of the set of samples analysed from month to month.

These samples were collected on different dates between the 16th November 1933 and the 24th of February 1934 from the cropped and the uncropped irrigated plots for turmeric on the Poona Agricultural College Farm. Total nitrogen and nitric nitrogen were determined as usua, along with the moisture in the soil. The moisture varied from 19 to 22 per cent.

The following table gives total nitrogen in both the cropped and the uncropped irrigated plots.

TABLE XII

Total nitrogen in mgs. per 100 grms. of oven-dry soil

Serial No.	Dates of samples	Cropped plot		Uncropped plot	
		0-in. to 6-in.	6-in. to 9-in.	0-in. to 6-in.	6-in. to 9-in.
		(Mgs.)	(Mgs.)	(Mgs.)	(Mgs.)
1	16th November 1933 . .	70·85	65·96	76·05	67·38
2	24th November 1933 . .	67·03	60·01	90·63	85·70
3	1st December 1933 . . .	76·33	69·39	77·14	73·13
4	18th December 1933 . .	74·95	67·43	75·60	74·54
5	23rd December 1933 . .	79·85	70·67	88·59	72·85
6	27th December 1933 . .	84·04	63·15	83·03	70·23
7	9th January 1934 . . .	68·07	62·54	74·89	70·06
8	15th January 1934 . . .	77·03	68·08	75·28	64·76
9	24th January 1934 . . .	77·79	67·65	83·66	81·58
10	30th January 1934 . . .	69·74	71·15	94·21	82·58
11	5th February 1934 . . .	69·58	71·10	82·43	81·01
12	19th February 1934 . .	72·72	69·05	77·29	72·79
13	24th February 1934 . .	73·73	69·74	93·48	75·27

Table XII shows that the lower three inches generally contain less total nitrogen than the upper six inches and further that the trend of fluctuations is the same in the upper and lower layers. This shows that the inferences drawn by determining nitrogen fluctuations from the top six-inch layers are correct as far as the trend of total nitrogen fluctuations is concerned and also with regard to the recuperation of nitrogen by the soils.

Figures for nitric nitrogen from the irrigated cropped and uncropped plots are interesting. They are given in Table XIII.

TABLE XIII

Nitric nitrogen in mgs. per 100 grms. of oven-dry soil

Serial No.	Dates of samples	Cropped plot		Uncropped plot	
		0 in. to 6 in.	6 in. to 9 in.	0 in. to 6 in.	6 in. to 9 in.
		(Mgs.)	(Mgs.)	(Mgs.)	(Mgs.)
1	16th November 1933	1·20	1·48	1·68	1·62
2	24th November 1933	1·20	1·04	2·87	1·71
3	1st December 1933	1·34	1·40	3·51	2·28
4	18th December 1933	1·67	1·44	2·13	1·50
5	23rd December 1933	1·65	1·68	4·15	1·63
6	27th December 1933	2·63	1·21	3·91	2·30
7	9th January 1934	1·74	1·14	3·25	2·07
8	15th January 1934	1·39	1·58	2·14	1·29
9	24th January 1934	2·29	1·80	3·62	2·54
10	30th January 1934	1·66	1·58	2·34	2·63
11	5th February 1934	0·92	1·42	2·50	3·60
12	19th February 1934	2·11	2·85	2·54	2·43
13	24th February 1934	2·17	1·48	2·83	2·21

These figures show that the nitric nitrogen in the cropped plot both for the upper six inches and the lower three inches of soil is invariably less than that in the uncropped plot. In the uncropped plot the nitric nitrogen in the upper six inches is generally higher than that in the lower three inches of soil. No such relation is seen in the nitric nitrogen of the cropped plot. The figures for the two layers do not differ much from each other.

IV. NITROGEN FLUCTUATIONS IN SOILS WHICH ARE IRRIGATED AND ARE UNDER CROP ALL THE YEAR ROUND

At Belgaum a rainfall crop of rice is followed by irrigated crops of vegetables. There is a system of taking three crops in a year and the land is cropped in the same manner year after year. There is the monsoon crop of rice from July to October. When the rice crop is removed the land is ploughed and ordinarily manured with farmyard manure at the rate of 7·5 tons per acre. Suitable beds are made for irrigation and a mixed crop of cabbage, knolkhol and potatoes is grown. This crop is on the land till the middle of April. A top dressing of ammonium sulphate (160 lbs. per acre), super-phosphate (112 lbs. per acre) and potassium sulphate (112 lbs. per acre) is given in the months of January and December. In the second half of April the land is harrowed and sweet potato cuttings are planted. This crop is removed in the form of cuttings in the month of June. The remaining portion is uprooted, the land is harrowed three times and prepared for drilling rice in July. The actual operations done on the plots under experiments are given in Table XIV.

TABLE XIV

Agricultural operations on the plots under experiment at Belgaum during 1933-34

Operations	Dates
Three harrowings	In May 1933
Drilling of rice seed (90 lbs. per acre)	22nd June 1933
Light interculturing and *Pesati* operation . . .	5th July 1933
Interculturing and *Pesati* operation	15th July 1933
Twice interculturing	1st August 1933 and 10th August 1933
Hand weeding	8th September 1933
Harvesting of rice	17th November 1933
Ploughing	18th November 1933
Manuring with farmyard manure (2½ tons per acre) and groundnut shell manure (7½ tons per acre). Harrowing and preparing beds for planting	12th December 1933
Planting of cabbage, etc., manuring with super-phosphate (112 lbs. per acre) and potassium sulphate (112 lbs. per acre)	15th December 1933
Well irrigation from 18th December to 9th June 1934 on every fourth day approximately	In all there were 29 irrigations given to the plots.
Weeding with *Fawada* and manuring with sulphate of ammonia (160 lbs. per acre)	19th January 1934
Weeding and pruning of leaves	5th March 1934
Removal of knolkhol	7th April 1934
Weeding and planting of sweet-potato creepers . .	20th April 1934
Removal of cabbages	28th April 1934
Removal of cabbages	7th May 1934
Weeding by hand	13th May 1934
Removal of cabbages	29th May 1934
Removing of sweet-potato creepers	25th June 1934
Removing of sweet potato creepers. Removing of weeds, uprooting of sweet-potato creepers, harrowing crosswise and sowing of paddy . . .	16th July 1934
Hand weeding	7th August 1934

The climatic data of Belgaum are given in Appendix B.

The soil at Belgaum on which the experiments were carried out is a mixture of material derived chiefly from laterite and partially from the Deccan trap. The soil is three feet deep and overlies laterite rock. It is well drained and is under cultivation for many years past.

A suitable piece of land was divided into three adjacent plots each measuring 33 ft. × 33 ft. Plot A was irrigated, manured and cropped ; plot B was manured and irrigated but had no crop, while plot C was only irrigated but had neither manure nor any crop. The samples of soils were collected from July 1933 to July

1934, at the beginning of every month. This cycle gives one overlapping sample for July. The collection of samples was done as already stated by randomising twelve spots for each plot, and taking composite sample by mixing twelve samples. Fig. 3 will give an idea as to how the twelve spots for soil samples were distributed for the month of June 1934 only. As all the three plots were under heavy rains and were irrigated every fourth day from the end of the rainy season of 1933 to the beginning of rains in 1934, the soil temperatures of the three plots taken on the same day did not vary beyond one °C. and the moistures not beyond one per cent. and hence in Table XV below, temperature and moisture of soil in plot A only are given to prevent unnecessary repetition. Only total nitrogen contents are taken in this table for three plots while nitric nitrogens are considered further on.

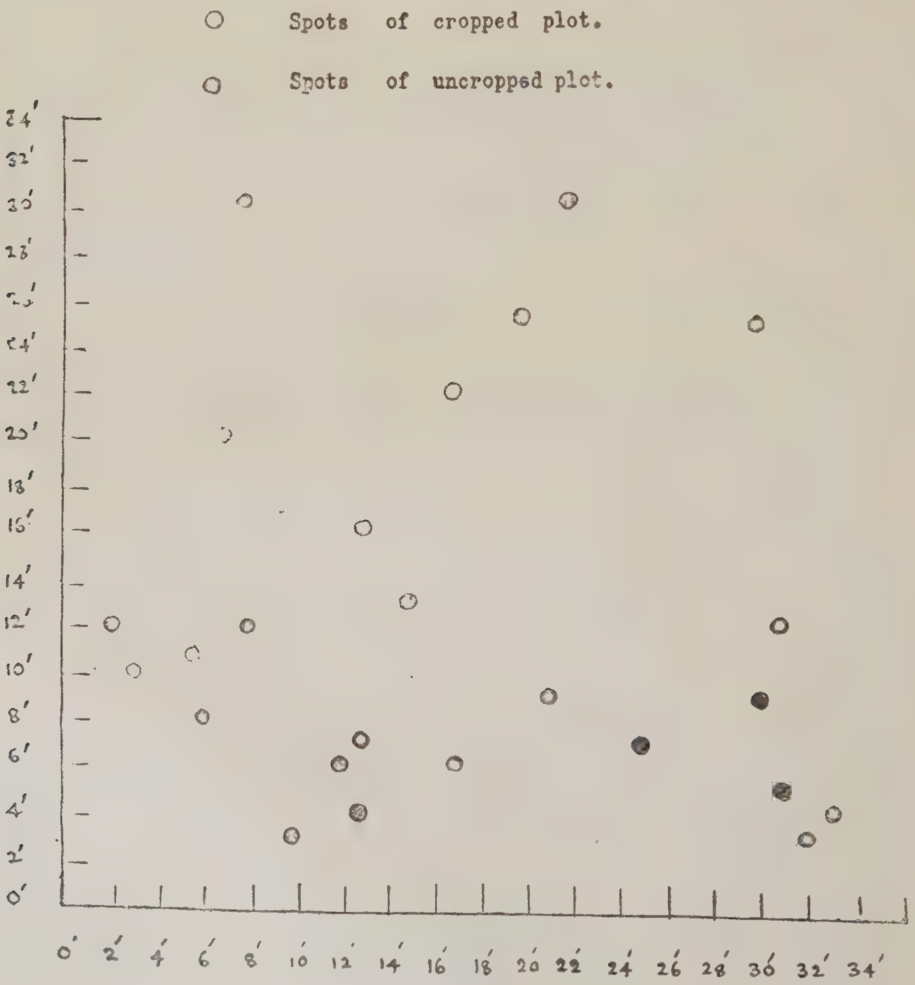

Fig. 3. Showing the distribution of the twelve spots of soil samples at Belgaum for June 1934.

TABLE XV

Soil temperature, moisture, pH values, total nitrogen in mgs. per 100 grams of oven-dry fine soil

Time	Soil temperature	Soil moisture	A		B		C	
			pH value	Cropped and manured	pH value	Uncropped and manured	pH value	Uncropped and unmanured
1933	°C.	Per cent		(Mgs.)		(Mgs.)		(Mgs.)
First week of—								
July	..	28·65	7·99	205·09	7·99	205·09	7·99	205·09
August	..	43·16	8·01	213·57	8·12	225·19	8·08	200·46
September	..	43·16	7·83	242·89	7·76	221·74	7·89	212·93
October	26·0	34·28	7·32	240·19	7·46	225·00	7·78	236·47
November	26·5	34·21	7·85	256·94	8·04	211·84	7·94	216·15
December	23·7	34·34	7·94	216·18	7·93	233·32	7·89	204·07
1934								
January	23·1	30·78	7·97	203·51	8·06	222·10	8·01	210·26
February	28·3	27·20	7·91	222·12	7·96	203·63	7·97	208·52
March	28·2	27·03	8·09	220·91	8·01	216·60	8·04	199·48
April	28·7	25·89	8·08	211·83	8·03	221·96	8·05	197·69
May	33·3	23·49	7·95	216·37	8·15	206·39	8·15	207·00
June	26·0	23·24	8·12	221·06	8·08	234·42	8·09	209·44
July	..	43·16	7·92	228·76	8·16	218·89	7·93	198·70

In considering the figures in Table XV three periods may be taken. The first from July to November when the rice crop is growing, no manure is added to any plot and there is no irrigation, but all the plots get rain water. The second period is from November to April. In this period all the three plots get well-irrigation. Plots A and B get organic manure in the beginning of December and plot A has vegetables like cabbage, etc., growing. The third period is from April to July when no manure is added, all the plots are irrigated and plot A has sweet-potato creepers growing.

During the first period the total nitrogen in all the plots increases. When the crop is growing usually the nitrogen in the cropped plot should be less than that of the uncropped plot as in the case of turmeric, but contrary to this the results of the plots at Belgaum show that when the rice crop is growing the nitrogen in the cropped plot is much higher than that in the uncropped plots.

The highest rise in plot A is in November. In plot B the rise occurs in December while in plot C it occurs in October. Soon after the rice crop is removed the total nitrogen in plot A falls and the total nitrogen figures of plot A are nearly the same as or even less than those of plot B. This may be due to the presence of vegetable crop on plot A as is in the case of turmeric plot at Poona. The unmanured plot C contains less of total nitrogen than the manured plot B practically all along. One striking fact comes out of the figures of total nitrogen given for plots A, B and C. The plot A with the rice crop growing on it shows more nitrogen than the uncropped plot while the same plot with vegetables growing on it shows less nitrogen than the plot without a crop. Plot C, which was neither cropped nor manured, shows less nitrogen in July 1934 than in July 1933. This is because it got no organic matter during 1934. Plot B, which was uncropped but got the same manure as plot A, shows more nitrogen in July 1934 than in July 1933. This is a distinct effect of the addition of organic matter in December 1933. The July 1934 figure for plot A, which was both manured and cropped, is higher than that for plot B. Plot B shows the advantage of manure over no manure and plot A shows the advantage of the cropped over uncropped.

The total quantity of manure added contains one milligram of nitrogen in 100 grams of soil in six inch acre. This is a very small quantity compared to the fluctuation in total nitrogen from month to month, before or after the manure was given.

The maximum fluctuation in plot A is from 203·51 milligrams per 100 grams of oven-dry, fine soil in January to 256·94 milligrams in November, which is 26·25 per cent.

The maximum fluctuation in plot B is from 203·63 milligrams per 100 grams of oven-dry, fine soil in February to 233·32 milligrams in December which is 14·58 per cent.

The maximum fluctuation in plot C is from 197·69 milligrams per 100 grams of oven-dry, fine soil in April to 236·47 milligrams in October which is 19·61 per cent.

The pH values of the cropped plot A vary from 7·92 to 8·18. They show a slight fall during the months of September, October and November and practically remain the same for the other months. The other plots behave very much in the same way. The range of the uncropped, manured plot B is from 7·46 to 8·16 while for the uncropped, unmanured plot C it is 7·78 to 8·15.

The quantities of nitric nitrogens of the same plots are given in Table XVI.

TABLE XVI

Nitric nitrogen in mgs. per 100 grams of oven-dry soil

Time	Soil temperature	Soil moisture	Cropped and manured	Uncropped and manured	Uncropped and unmanured
1933					
First week of	°C.	Per cent	(Mgs.)	(Mgs.)	(Mgs.)
July	..	28·65	0·51	0·51	0·51
August	..	43·16	0·33	0·42	0·48
September . . .	..	43·16	0·33	0·05	0·10
October . . .	26·0	34·28	0·39	0·51	0·57
November . . .	26·5	34·21	0·49	0·37	0·96
December . . .	23·7	34·34	0·34	0·35	0·64
1934					
January . . .	23·13	30·78	0·73	2·25	0·70
February . . .	28·25	27·20	1·45	0·99	1·09
March	28·16	27·03	0·95	1·37	1·31
April	28·70	25·89	0·93	4·10	2·82
May	33·30	23·49	0·75	2·69	2·74
June	26·0	23·24	3·82	4·88	6·01
July	..	43·16	0·35	0·55	0·52

One fact is clear from the above figures that after the rice crop is harvested the uncropped plots contain more of nitric nitrogen than the cropped plot.

The water for irrigation at Belgaum contained appreciable quantities of nitrogen, especially in the form of nitrates amounting to 2·86 parts nitrogen per 100,000 parts of water. There were in all twenty-nine irrigations from the middle of December to the beginning of June 1934. The total quantity of nitrogen added through irrigation amounted to less than two milligrams per 100 grams of soil. This is perhaps the reason why there is a regular rise in nitrates in all the three plots from January onwards. The uncropped plots naturally show more nitrates than the cropped one. As soon as irrigation is stopped in the beginning of June the rains set in and the nitrates are washed away rapidly. Although the amount of nitrogen added through irrigation is sufficient to influence the increase in nitrates in the soil, it cannot account for the fluctuations in total nitrogen which are far greater than the nitrogen added by irrigation.

V. Nitrogen fluctuations in soil under heavy rainfall conditions

Experiments described in the previous sections furnished data for nitrogen fluctuations in soil under irrigation and with high rainfall followed by irrigation. A set of experiments was arranged at Karjat about sixty miles from Poona on the Bombay-Poona line, to study the nitrogen fluctuations in soils under heavy rainfall. On the Government Experimental Farm at Karjat, an area was divided into two equal plots adjacent to each other measuring 33 ft. × 33 ft. each. On one plot transplanted rice was grown and the other was left without a crop but received water and all other treatments just as the cropped plot. No plot received any manure. The usual practice is to plough the land as soon as the first monsoon rains are received. There is a second ploughing after about a fortnight. The land is puddled and planked in July just before transplanting rice seedlings. The crop is harvested in November.

The climatic data of Karjat are given in appendix C.

Usually washings from the upper fields are allowed to run in to the lower fields. This was not allowed in the experimental plots. The rain water was allowed to accumulate in beds, and excess allowed to run out.

The soil of the plots under experiment is one and a half feet deep lying over trap. The samples of soils were taken as previously described by randomisation and by preparing a composite sample from twelve spots from month to month. Fig. 4 will give an idea as to how the twelve spots for soil samples were distributed for the month of July 1933 only. Temperatures and mositures for both the plots were nearly the same, temperature varying within one °C. and moisture varying within one per cent. The total nitrogen figures are given in Table XVII.

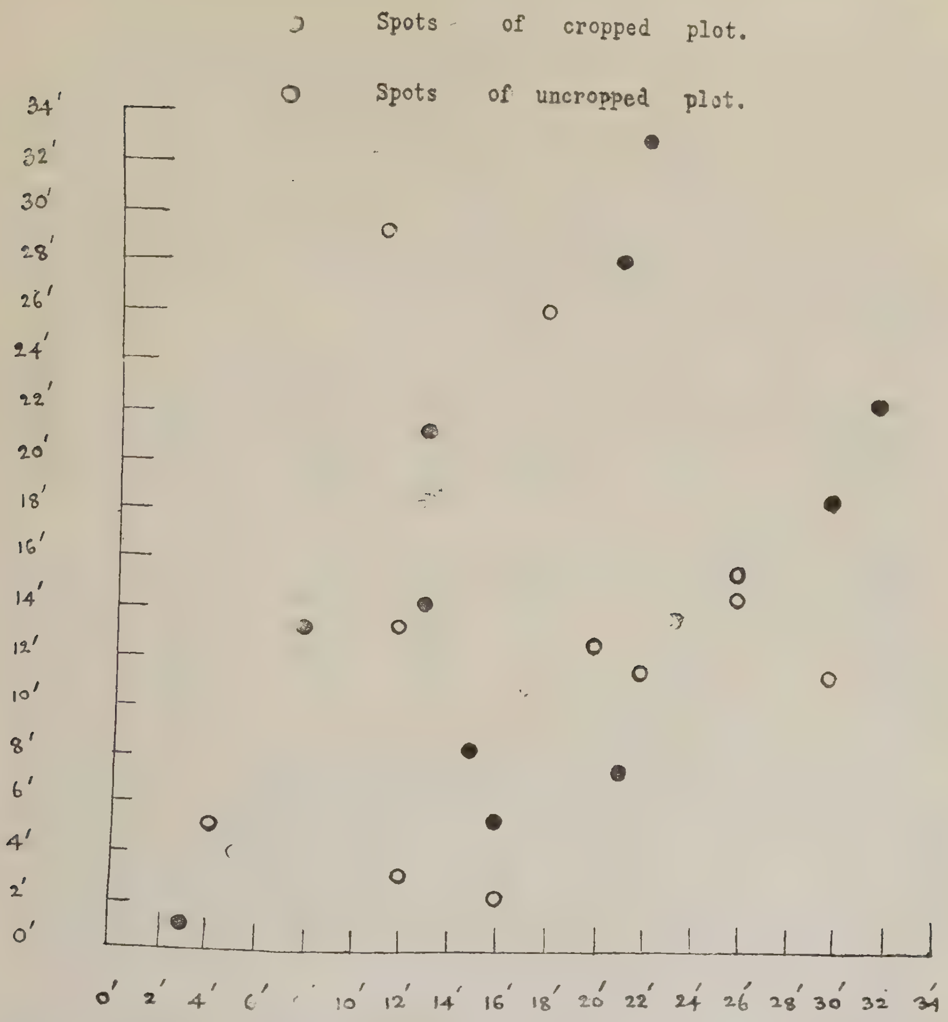

Fig. 4. Showing the distribution of the twelve spots of soil samples at Karjat for July 1933.

TABLE XVII

Temperature and moisture of the soil, pH values and total nitrogen in mgs. per 100 grams of oven-dry, fine soil

Time	Soil temperature	Soil moisture	pH value	Total nitrogen cropped plot	pH value	Total nitrogen uncropped plot
1933						
Second week of—	°C.	Per cent				
July . .	. .	40·22	7·69	86·21	7·69	86·21
August .	. .	40·22	7·61	86·00	7·21	85·90
September .	. .	40·22	7·76	87·77	7·51	82·39
October .	30·2	36·80	7·78	83·78	7·53	82·58
November .	24·7	34·26	7·90	91·72	7·74	83·66
December .	26·7	16·71	7·97	88·60	7·73	84·50
1934						
January .	27·1	6·78	7·98	89·67	7·73	84·73
February .	32·0	6·66	8·03	86·11	7·71	82·46
March . .	39·3	6·65	7·91	86·05	7·70	86·29
April . .	44·6	6·40	7·90	86·92	7·68	83·94
May . .	40·4	6·94	7·85	82·04	7·64	84·85
June . .	26·0	33·15	7·95	87·67	7·56	85·15
July . .	. .	40·22	7·64	88·28	7·64	81·19

In the uncropped plot the total nitrogen is practically the same from beginning to end except that there is a fall in the month of September 1933 and a fall again in July 1934 and a rise in March 1934. The other fluctuations are not much beyond working error. On the cropped plot, nitrogen is nearly steady during July, August and September, falls in October and rises distinctly in November. It is then nearly constant till January 1934 and comes down further and remains nearly at the same level throughout.

There is an important difference in the cropped and the uncropped plot. The cropped plot being almost always higher than the uncropped plot in total nitrogen. At the end of the cycle, the uncropped plot is lower in nitrogen than it started with, on account of the absence of crop and therefore for want of addition of organic matter. The cropped plot which receives organic matter in the form of roots and stubbles keeps its nitrogen contents at a higher level than the uncropped plot.

Here again it is seen that during the life time of the crop the nitrogen is higher in the cropped than in the uncropped as in the case of rice plots at Belgaum. It can therefore be stated that during the life time of the crop the cropped plot was higher because of the presence of rice crop and after the crop was harvested, the cropped plot had the advantage of the crop residues. The lowest figure of total nitrogen is 81·19 milligrams per 100 grams of oven-dry soil in July 1934 and the highest is 86·29 milligrams per 100 grams of oven-dry soil in March 1934. The maximum fluctuation therefore is 6·27 per cent in the uncropped plot.

In the cropped plot the lowest total nitrogen is 82·04 milligrams per 100 grams of oven-dry soil in May 1934 and the highest is 91·72 milligrams per 100 grams of oven-dry soil in November 1933. The highest fluctuation therefor is of 11·8 per cent.

Both the cropped and the uncropped plots show but very little change in the pH values. Values are very slightly lower in the rains than in the other seasons. The range of the cropped plot is from 7·61 to 8·03 while that of the uncropped plot is from 7·21 to 7·74.

TABLE XVIII

Temperature and moisture of the soil and nitric nitrogen in mgs. per 100 grams of oven-dry, fine soil

Time	Soil temperature	Soil moisture	Nitric nitrogen in cropped plot	Nitric nitrogen in uncropped plot
1933 Second week of—	°C.	Per cent		
July	..	40·22	0·38	0·38
August	..	40·22	0·04	0·13
September	..	40·22	0·23	0·30
October	30·2	36·80	0·10	0·22
November	24·7	34·26	0·37	0·13
December	26·7	16·71	0·53	0·50
1934				
January	27·1	6·78	0·37	0·35
February	32·0	6·66	0·33	0·43
March	39·0	6·65	0·32	0·41
April	44·6	6·40	0·31	0·39
May	40·4	6·94	0·15	0·13
June	26·0	33·15	0·42	0·34
July	..	40·22	0·20	0·17

The nitric nitrogen is low during rains both in the cropped and the uncropped plots, but lower in the cropped than in the uncropped. From November onwards the nitrates rise and reach the highest point in December, slowly fall till May, rise again in June and begin to fall in July.

VI. DISCUSSION OF RESULTS

So far the results of each set of experiments have been discussed separately under each section. It is necessary now to consider the results of all the sets taken together in order that the conclusions arrived at may be of general application. The results obtained may be considered under the following heads :—

(1) Relation of organic matter in the soil to the total nitrogen, (2) fluctuation in total nitrogen, (3) conditions under which the highest point of total nitrogen is reached, (4) conditions under which the lowest level in total nitrogen is reached, (5) effect of manuring and cropping, (6) fluctuation in the nitric nitrogen, and (7) general.

(1) *Relation of organic matter to total nitrogen*

In finding out this relation it is better to consider only the uncropped and unmanured plots and compare the highest and lowest levels of total nitrogen with the proportion of organic matter in the soil. It is seen from the following figures that both the highest and the lowest levels of total nitrogen are higher in soils with larger proportion of organic matter.

TABLE XIX

Relation of organic matter to total nitrogen in soils

Plots	Organic matter	Per 100 grams of oven-dry, fine soil	
		Highest point of total nitrogen	Lowest point of total nitrogen
	Per cent	(Mgs.)	(Mgs.)
Poona *juar* (uncropped)	1·53	51·07	41·22
Karjat rice uncropped	1·81	86·29	81·19
Belgaum uncropped and unmanured (before manure was given to other plots)	4·44	236·47	197·69

At Belgaum organic matter as farmyard manure was added to plot B in December 1933 while plot C was not manured. In every other way both the plots were treated alike. Before the manure was added the total nitrogen of plot

C was not lower than that of plot B, but from January onwards plot B showed higher nitrogen than plot C and this might be put down as the effect of organic matter added (Fig. 5).

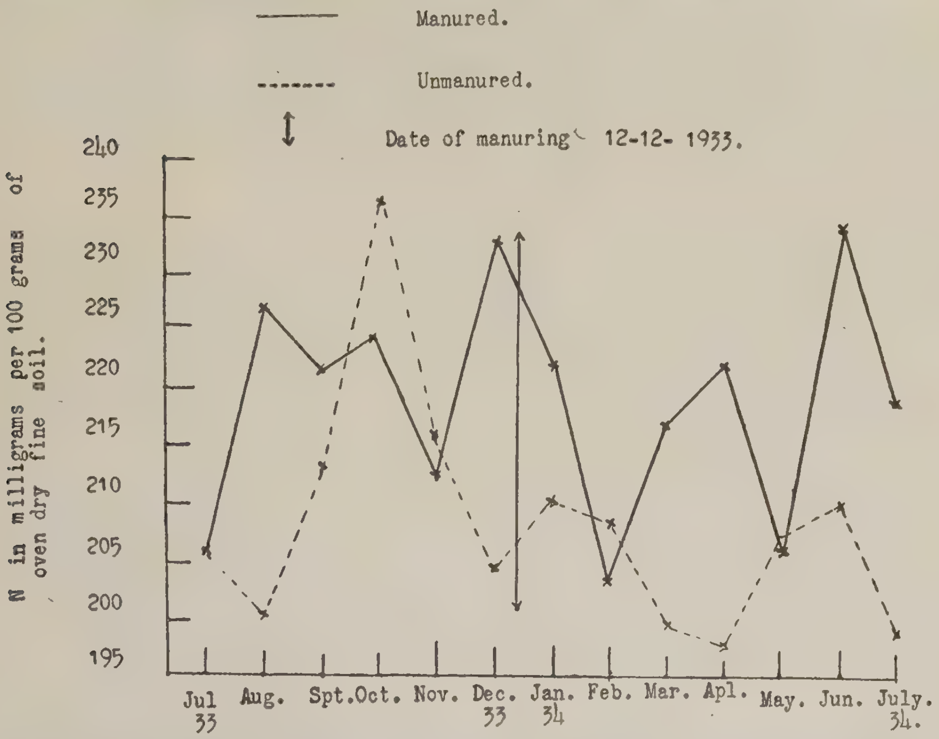

Fig. 5. Total Nitrogen in plots B and C at Belgaum (showing that manured plot B contains more total nitrogen than unmanured plot C after it is manured in the month of December).

TABLE XX

Total nitrogen in manured and unmanured plots

Plot	Condition	Per 100 grams of oven-dry, fine soil after manure was added	
		Highest point of total nitrogen	Lowest point of total nitrogen
C	Unmanured (after the other plot was manured in December)	210·26	197·69
B	Manured	234·42	203·63

(2) *Fluctuation in total nitrogen*

Fluctuation in total nitrogen does not seem to depend wholly on organic matter. It depends at least partially on the lime and the phosphoric acid contents of the soils [Sahasrabuddhe and Ghatikar, 1931]. Table XXI brings this out. It gives the organic matter, lime and phosphoric acid contents of the unmanured and uncropped soils with the maximum difference between the highest and the lowest proportions of total nitrogen and the percentage increase in each plot.

Table XXI

Soil constituents of unmanured and uncropped plots with the nitrogen fluctuations

Plot	Organic matter	Lime (CaO)	Phosphoric acid P_2O_5	Highest point of total nitrogen	Lowest point of total nitrogen	Per cent increase
	Per cent	Per cent	Per cent	(Mgs.)	(Mgs.)	Per cent
Poona (*juar*) uncropped .	1·53	6·17	0·054	51·07	41·22	23·1
Belgaum uncropped . .	4·44	1·05	0·36	236·47	197·69	19·6
Karjat uncropped	1·81	0·92	0·11	86·29	81·19	6·3

The larger the proportion of lime, the greater is the fluctuation in total nitrogen modified by the proportion of phosphoric acid. The actual quantity of total nitrogen may depend on the organic matter but the fluctuation appears to be affected by the proportion of lime and phosphoric acid contents [Sahasrabuddhe and Ghatikar, 1931]. The Karjat soil which contains only a small proportion of lime shows a very small fluctuation.

(3) *Conditions under which the total nitrogen reaches the highest point*

The highest point of total nitrogen is affected by many factors. Ordinarily the total nitrogen is high during the cold season from November to February. Although the minimum air temperatures in these months are low they are rarely so low as to interfere with the reactions in the soil. The maximum temperatures and the moistures in the soil taken together are favourable for the reactions taking place in the soil. In the cold season the minimum air temperatures may go as low as 8°C. to 10°C. and there is, under these circumstances, sometimes, a fall in total nitrogen in the unirrigated plots as will be seen from the total nitrogen figures for January for the *juar* plots at Poona. During the cold season the mean maximum air temperatures varied from 27°C. to 34°C. and the mean minimum air temperatures varied from 8°C. to 24°C. The soil temperatures at 5 P. M. on the days of taking samples varied between 27°C. and 33°C. Sometimes another high figure for total nitrogen is obtained in June when the soils which get heated during summer are wetted by June rains.

TABLE XXII

Showing the plots and the months in which the highest or very nearly the highest figures for total nitrogen are obtained

Plots	Months
Poona *juar* cropped plot	December and September.
Poona *juar* uncropped plot	December and June.
Poona turmeric cropped plot	December and June.
Poona turmeric uncropped plot . . .	February and June.
Belgaum manured, cropped and irrigated plot .	November.
Belgaum manured, uncropped and irrigated plot	December and June.
Belgaum unmanured, uncropped and irrigated plot	October.
Karjat rice cropped plot	November.
Karjat rice uncropped plot	January and June.

(4) *Conditions under which the total nitrogen reaches the minimum level*

The minimum figures for total nitrogen do not fall in any particular month—the month changing with the treatment of the soil. The total nitrogen, however, is generally low in the hot weather when the moisture goes down. The lowest figures are in many cases in May because the moisture is very low. But sometimes very low figures of total nitrogen are also obtained in the rainy season, perhaps on account of the washing away by rains. Belgaum plots being irrigated for eight months form exceptions to the above statement.

TABLE XXIII

Showing the plots and the months in which the minimum level of total nitrogen is reached

Plots	Months
Poona *juar* cropped plot	July.
Poona *juar* uncropped plot	May.
Poona turmeric cropped plot	August.
Poona turmeric uncropped plot	May.
Karjat rice cropped plot	May.
Karjat rice uncropped plot	September.

For Belgaum plots, although the lowest figures are not in May, still the total nitrogen figures in the hot season are, on the whole, low.

(5) *The effect of cropping on the total nitrogen of soils*

The effect of crop on the total nitrogen is not the same with all the crops. The *juar* plots at Poona and the rice plots at Karjat show that the cropped plots contain more total nitrogen than the uncropped plots, both during the growing period of the crops and also after they are removed. At Belgaum during the growing period of rice, the cropped plot A contains more total nitrogen than the uncropped plots B and C. But when vegetables are planted after rice in Belgaum the same plot A shows less nitrogen in certain months than the uncropped plot B (treated exactly like A except for the crop). The turmeric plots at Poona show that when turmeric is growing on the land from July to March the cropped plot has less total nitrogen than the uncropped one. But as soon as the crop is removed, the cropped plot gets better than the uncropped plot. The question as to which crops help nitrogen recuperation during their growing period must form a problem by itself for an independent investigation (Figs. 6, 7, 8, and 9).

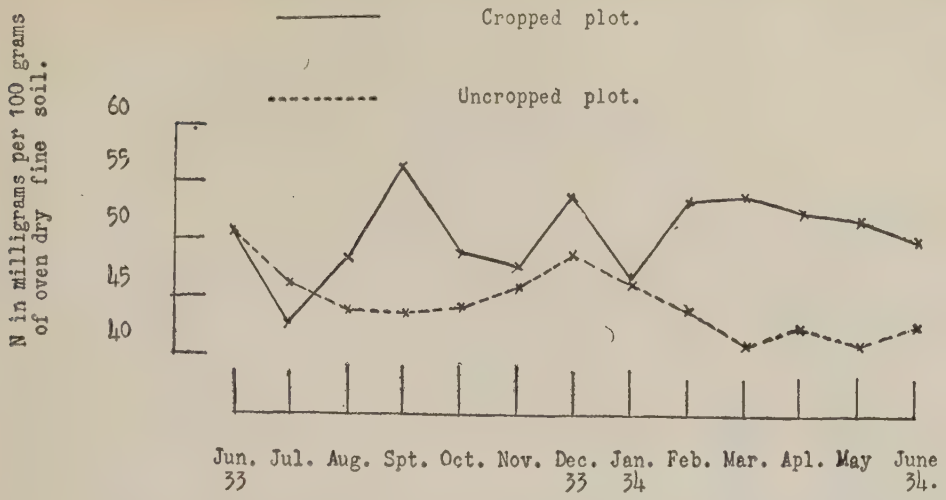

Fig. 6. Total nitrogen in *juar* plots, Poona (showing that the cropped plot always contains more total nitrogen than the uncropped plot).

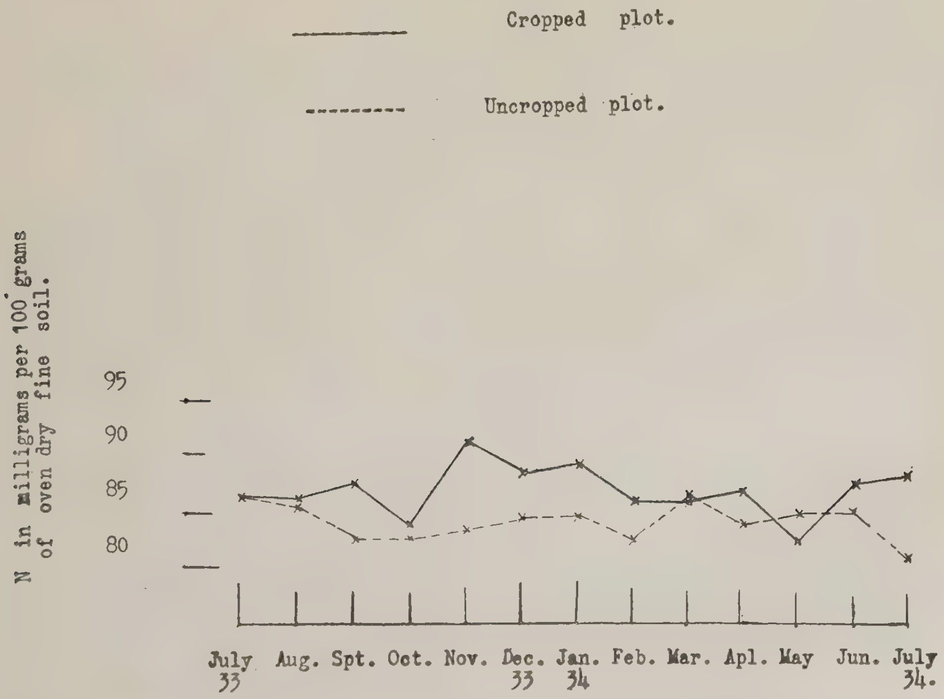

Fig. 7. Total nitrogen in rice plots at Karjat (showing that the cropped plot contains more total nitrogen than the uncropped plot).

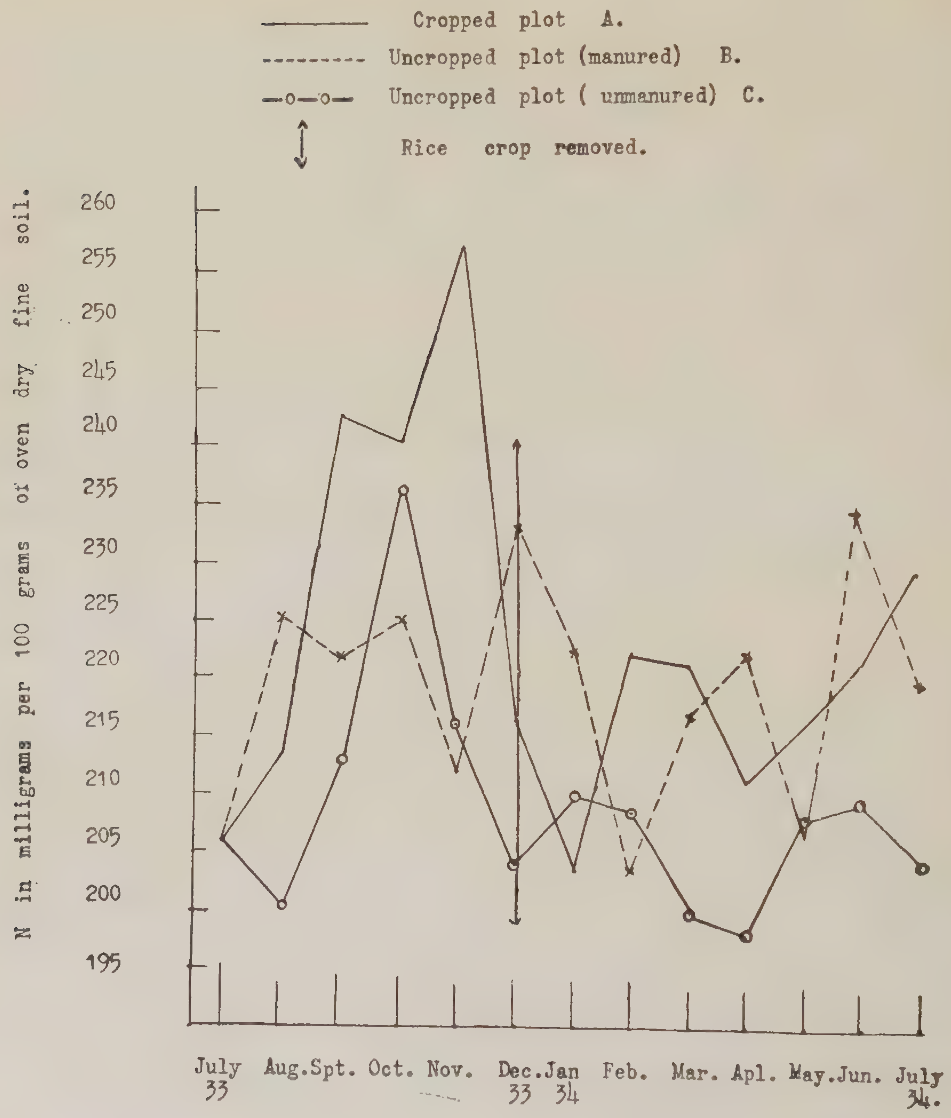

Fig. 8. Total nitrogen in plots A, B and C at Belgaum (showing that during the growing period of rice, the cropped plot A contains more total nitrogen than the uncropped plots B and C).

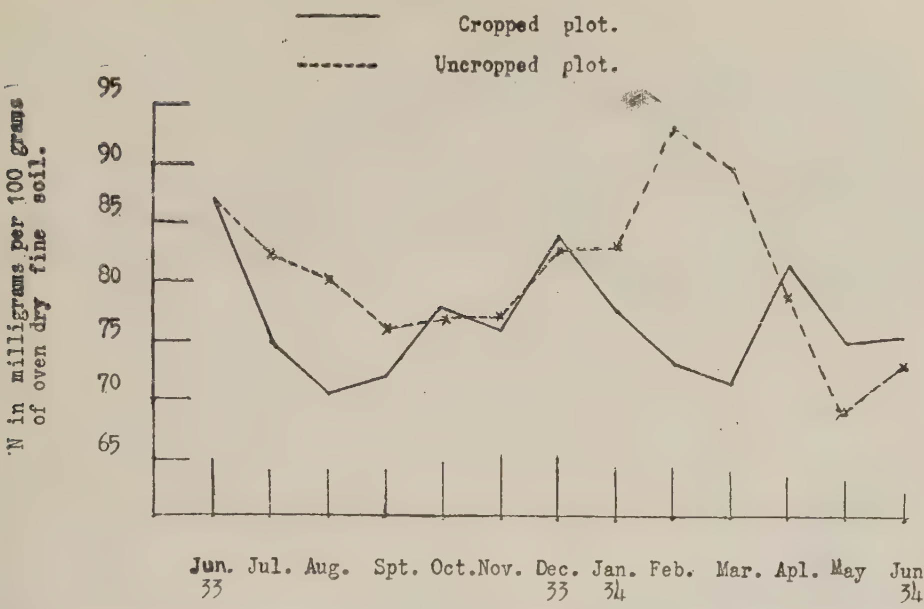

Fig. 9. Total nitrogen in turmeric plots, Poona (showing that the total nitrogen in uncropped plot is more than the cropped plot during the period while crop is on the land. After it is removed in March the total nitrogen in uncropped plot becomes less than the nitrogen in the cropped plot as in April 1934).

Although during the growing period of the crop, all crops do not show the same effect on the total nitrogen, yet after the crop is removed the residues of the crop left in the soil help the cropped plot to get more nitrogen than the uncropped ones in all the cases studied. Cropping therefore has a good effect. Manuring and cropping affect the total nitrogen in general and the highest point reached. The lowest figures however are affected only slightly and that too only at times as is seen from Table XXIV given below.

Table XXIV

Comparison of minimum total nitrogens in the cropped and the uncropped plots (Mgs. per 100 grms. of oven-dry soil)

Crop and place	Cropped plots	Uncropped plots
Juar at Poona	43·38	41·22
Turmeric at Poona	70·59	69·11
Rice at Belgaum	203·51	203·63
Rice at Karjat	82·04	82·46

(6) *Fluctuations in nitric nitrogen*

With the exception of the Belgaum plots, which may be considered separately, it is observed that all the plots, both cropped and uncropped, show high proportion of nitric nitrogen during the cold season from November to February when the moisture and temperature conditions taken together are favourable for nitrification. Sometimes nitrification is active in June when the soils get wetted after being heated in the hot season. The lowest figures of nitric nitrogen are in the middle of the rainy season, since the nitrates are perhaps washed away by rains (Figs. 10, 11, 12 and 13).

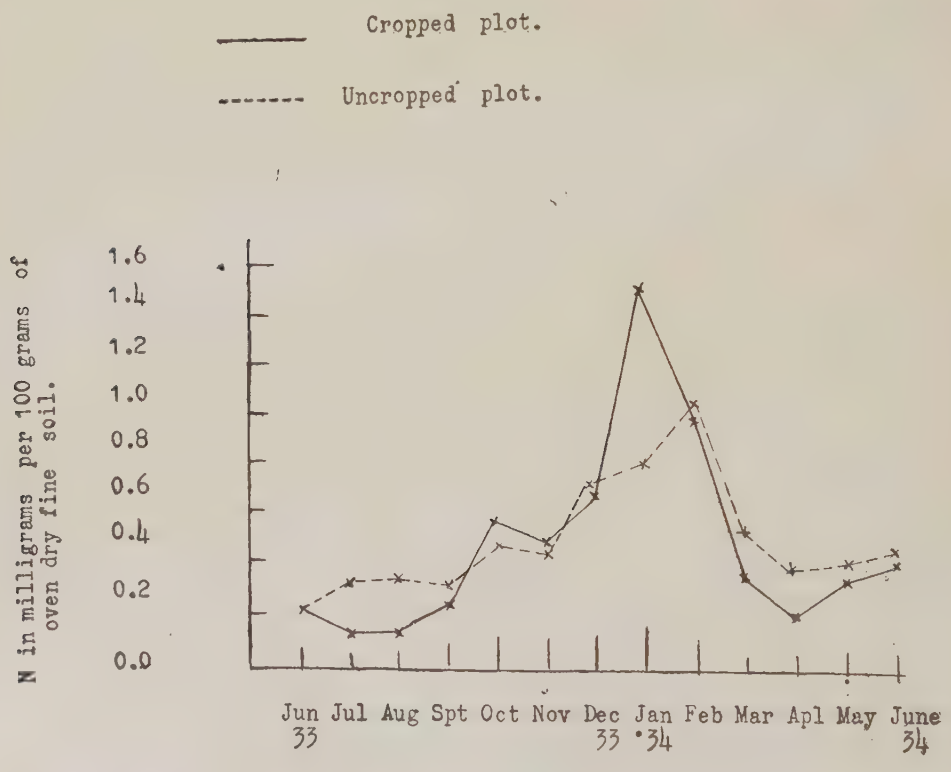

Fig. 10. Showing the nitric nitrogen in cropped and uncropped plots of *juar* at Poona.

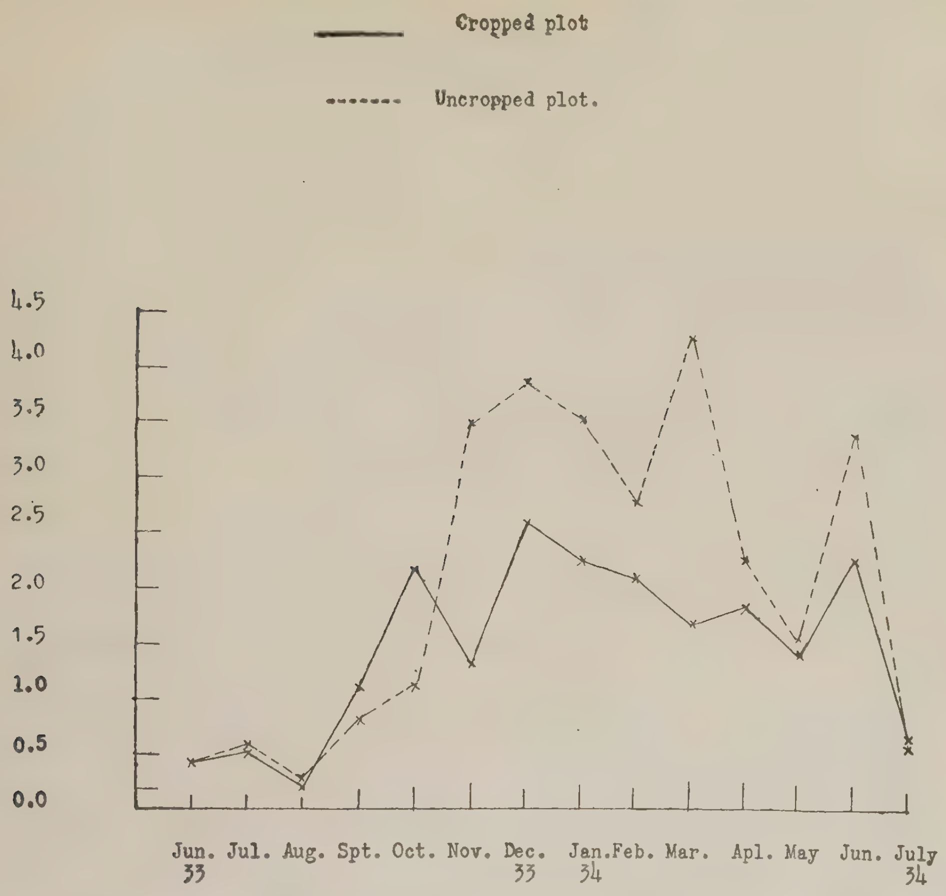

Fig. 11. Showing the nitric nitrogen in cropped and uncropped plots of turmeric at Poona.

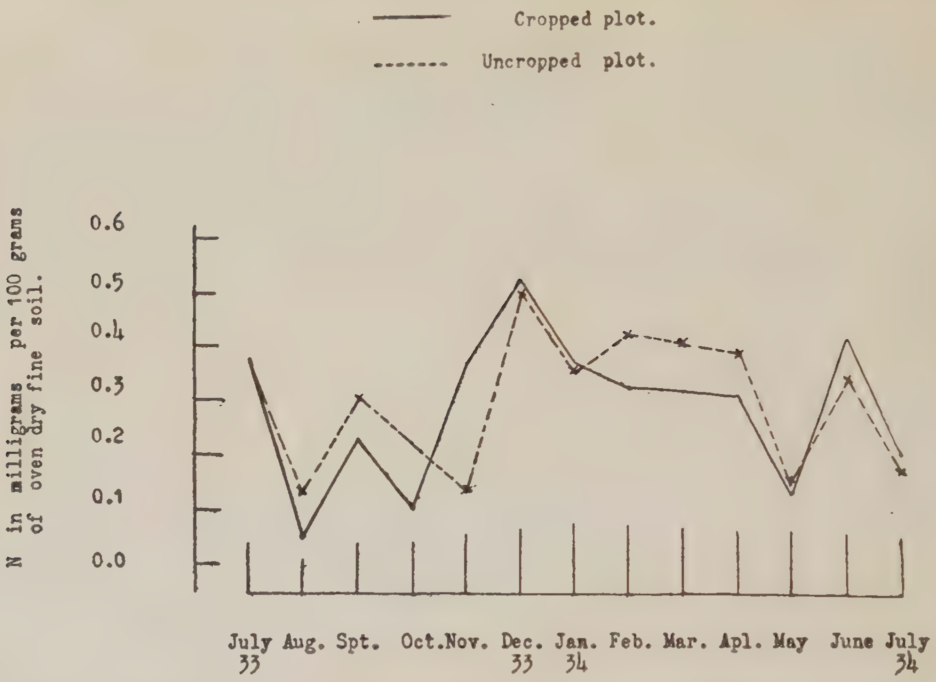

Fig. 12. Showing the nitric nitrogen in cropped and uncropped plots at Karjat.

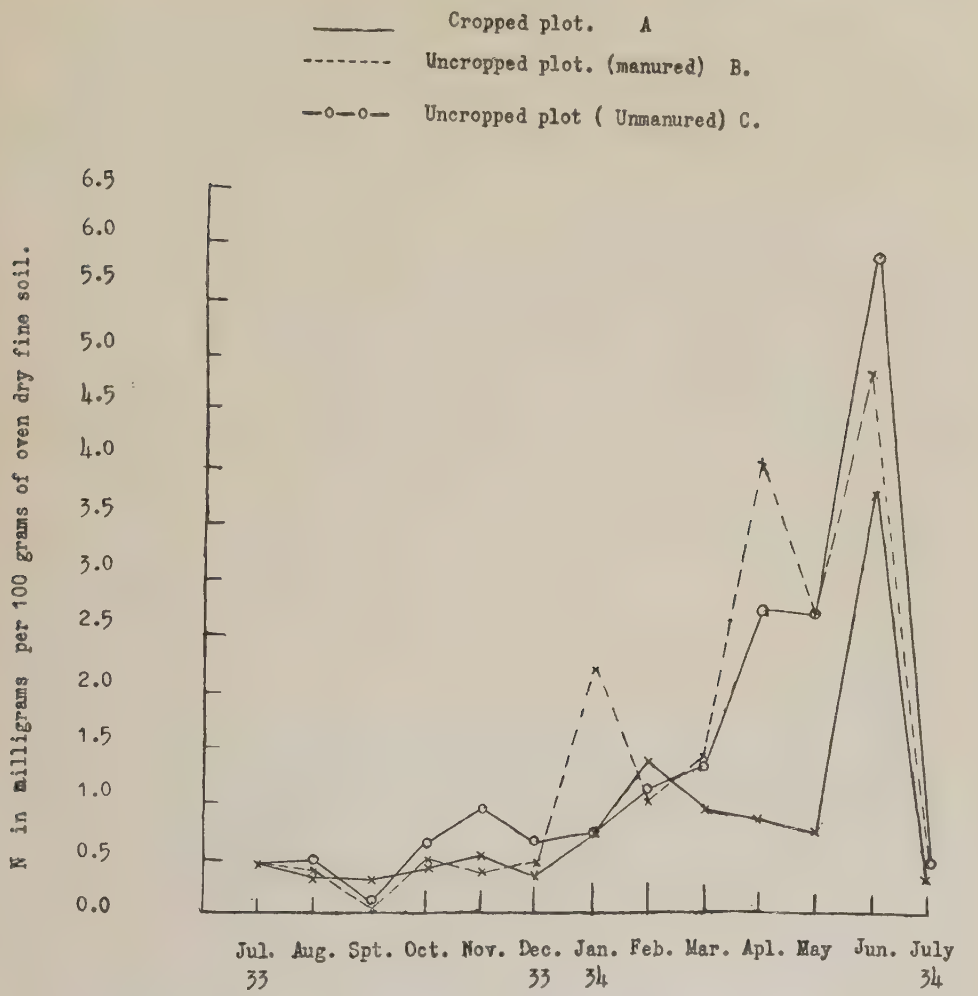

Fig. 13. Showing the nitric nitrogen in plots A, B and C, at Belgaum.

TABLE XXV

Showing the plots and the months showing minimum and maximum nitric nitrogen

Plots and places	Months of minimum nitric nitrogen	Months of maximum nitric nitrogen
Poona *juar* cropped plot	July and August	January
Poona *juar* uncropped plot	July	February
Poona turmeric cropped plot	August	December
Poona turmeric uncropped plot	August	December and March
Karjat rice cropped plot	August	December
Karjat rice uncropped plot	August and May	December

Generally the nitric nitrogen is higher in the uncropped plots than in the cropped plots.

In the Belgaum plots the nitric nitrogen is low during the rains but the highest mark is not reached in the cold season but goes on increasing till June. This is so because the plots were irrigated from November to June with water which contained nitrates. The difference due to the crop is clear at Belgaum because plots B and C which were not cropped show more nitric nitrogen than plot A which was cropped throughout the period from November to June.

(7) *General*

It is contended by some that the soil heterogeneity is so much that no accurate estimate of the various changes in nitrogen in soil can be obtained by carrying out experiments in the field. Such investigation must therefore be carried out under controlled conditions of the laboratory.

It may be made clear here that the study of the nitrogen recuperation was first done in the laboratory, under controlled conditions [Sahasrabuddhe and Daji, 1925 and Sahasrabuddhe and Ghatikar, 1931]. After definite results were obtained there, field experiments were undertaken to see what actually takes place under the usual conditions of cultivation and climatic changes.

In order to get an exact idea about the periodic fluctuations in the nitrogen of the soil it is necessary to study the changes for a cycle of twelve months and this was done in the investigation under consideration. All possible precautions were taken in collecting samples. The sampling error in experiments is small and the differences in the nitrogen contents of the soil cannot be put down to error of any kind. The plots chosen represent distinct types of cultivations. The results obtained are not erratic but show some regular tendencies in the changes as discussed above. The changes, therefore, must be taken as indications of what actually happens.

VII. Conclusions

1. The nitrogen of the soil, under the conditions of the Bombay-Deccan, is not a constant quantity. It fluctuates from month to month according to moistures and temperatures of the soil, which depend in their turn on the climatic conditions, thus confirming the results published by Sahasrabuddhe and Kanitkar [1932]. There is an annual cycle of these fluctuations, indicating regular loss and recuperation of nitrogen by the soils. This holds good not only for the *rabi* lands as shown by Sahasrabuddhe and Kanitkar [1932] but also for *kharif* dry lands, heavy rainfall lands and for lands under irrigation.

2. In the *kharif*, irrigated and heavy rainfall soils the highest point of total nitrogen is reached in cold season and some times in June also. The lowest level is reached in July or August, *i.e.*, in the middle of the rainy season or in May when the moisture is very low.

3. The larger the quantity of organic matter in the soil, the greater is the proportion of nitrogen in the soils.

4. Addition of organic matter as manure or in the form of roots and leaves of crops helps in fixing nitrogen by the soils.

5. The fluctuations in total nitrogen depend, at least partially, on the proportion of lime and phosphoric acid contents of soils.

6. During the growing period of a crop the cropped cultivated land is better than the uncropped cultivated land with certain crops, as rice and *kharif juar* but the reverse is the case with certain other crops, as irrigated vegetables and turmeric. This question however requires further investigation.

7. In all the cases studied it was observed that after the crop was removed the cropped soils were better in nitrogen than the uncropped ones.

8. When a soil is cultivated it is better to crop it than to leave it uncropped.

9. Nitric nitrogen is higher in cold season which extends from November to February and in June at the beginning of the rains.

10. During the life of the crop, the cropped plots contain less nitric nitrogen than the uncropped plots.

Acknowledgments

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REFERENCES

Bartholomew, R. P. (1932). *Univ. Arkansas Agric. Expt. StBull. No.* **270**, April 1932.

Crowther, E. M. and Mirchandani, T. J. (1931). *J. Agric. Sci.* **21**, 497.

Desai, S. V. (1933). *Ind. J. Agric. Sci.* **3**, Part II, April 1933.

Carlach, M. (1934). *Landw-Jahrb* **80**, 73-101.

Penman, F. and Rountree, P. (1932). *J. Agric. Victoria* **30**, 496-503.

Prescott, J. A. and Piper, G. R. (1930). *J. Agric. Sci.* **20**, Part IV, October 1930.

Rheinwald, H. (1933). *Z. Pflanz. Dung.* **30-A.**, 82-98 (extract in *J. Chem. Indus.* **52**, No. 36, September 1933).

Sahasrabuddhe, D. L. and Daji, J. A. (1925). *Mem. Dept. Agric. Ind., Chem. Ser.* **8**, No. 5.

Sahasrabuddhe, D. L. and Ghatikar, B. H. (1931). *Ind. J. Agric. Sci.* **1**, Part VI.

Sahasrabuddhe, D. L. and Kanitkar, N. V. (1932). *Ind. J. Agric. Sci.* **2**, Part V.

Sreenivasan, A. and Subrahmanyan, V. (1934). *J. Ind. Inst. Sci.* **17-A**, Part X, 113—126.

Vandecaveye, S. C. and Villanueva, B. R. (1934). *Soil Sci.* **38**, No. 3, 204.

Wilshaw, R. G. H. (1934). *Malayan Agric. J.* **22**, No. 1.

Appendix A

The climatic data noted on the Poona Agricultural College Farm for the year 1933-34.

Month and year	Rainfall during the month	Mean temperature of the month and of the week of sample taken		Mean humidity
		Maxima	Minima	
	(Inches)	(°C.)	(°C.)	(Per cent)
1933				
May	5·98	36·66	21·94	78·8
June	5·43	33·47	21·66	83·2
Week of sample . . .	3·23	27·22	20·55	93·0
July	5·89	29·30	21·66	88·4
Week of sample . . .	4·62	27·22	21·11	94·9
August	7·24	27·98	20·83	89·8
Week of sample . . .	0·29	29·44	20·55	86·5
September . . .	8·29	29·56	20·55	88·22
Week of sample . . .	0·85	31·11	19·44	85·50
October	1·51	31·02	18·46	85·6
Week of sample . . .	..	30·55	13·89	84·7
November . . .	0·21	30·96	13·68	77·6
Week of sample . . .	..	31·11	14·72	79·3
December . . .	1·00	25·97	9·93	82·4
Week of sample . . .	..	28·89	8·33	83·8
1934				
January	..	29·58	8·61	80·09
Week of sample . . .	..	30·55	10·55	78·1
February	..	33·68	9·44	71·6
Week of sample . . .	..	33·89	11·11	65·5
March	..	36·36	13·59	65·4
Week of sample . . .	..	40·00	16·90	62·7
April	..	40·05	22·29	65·1
Week of sample . . .	..	39·66	18·33	59·3
May	0·28	39·08	21·11	58·0
Week of sample . . .	..	38·33	22·22	59·22
July	3·90	32·56	21·80	78·1
Week of sample . . .	1·05	29·16	21·67	84·4

Appendix B

The climatic data noted at Belgaum for the year 1933-34

Month and year	Rainfall of the month and of the week in which the sample was taken	Mean temperature of the month and of the week of the sample taken		Mean humidity
		Maxima	Minima	
	(Inches)	(°C.)	(°C.)	(Per cent)
1933				
May	5·1	32·1	19·8	76·7
June	9·3	25·6	19·9	89·7
July	16·50	25·14	19·74	91·5
Week of sample	0·10	26·1	20·0	89·6
August	12·4	25·25	19·41	91·8
Week of sample	8·90	22·6	19·7	94·1
September	6·0	26·71	17·32	90·14
Week of sample	1·90	27·5	13·6	93·9
October	8·8	27·92	13·4	80·88
Week of sample	4·0	29·4	18·6	84·0
November	3·20	28·86	16·65	62·2
Week of sample	..	29·4	14·7	47·5
December	0·30	27·88	13·19	61·6
Week of sample	..	27·2	11·9	52·4
1934				
January	..	28·4	14·44	68·15
Week of sample	..	26·9	13·9	74·1
February	..	31·99	15·86	51·0
Week of sample	..	29·7	16·7	53·0
March	..	34·12	16·56	48·7
Week of sample	..	32·2	14·7	42·1
April	0·7	35·6	19·45	70·0
Week of sample	..	36·7	19·7	70·1
May	0·6	34·20	19·78	67·50
Week of sample	0·6	36·7	20·0	66·6
June	9·90	27·66	20·27	86·9
Week of sample	3·20	27·6	20·6	89·7
July	18·8	24·30	19·78	94·20
Week of sample	11·8	23·33	19·6	94·0

Appendix C

The climatic data noted at Karjat for the year 1933-34

Month and year	Rainfall of the month and of the week in which the sample was taken	Mean temperature of the month and of the week of the sample taken		Mean humidity
		Maxima	Minima	
	(Inches)	(°C.)	(°C.)	(Per cent)
1933				
May	5·10	35·83	24·20	71·60
June	27·64	30·53	22·50	84·20
July	44·97	28·24	23·90	86·90
Week of sample	6·56	28·89	23·89	82·70
August	45·53	27·60	22·90	84·90
Week of sample	2·82	28·89	23·59	89·60
September	24·86	29·00	23·60	89·20
Week of sample	6·31	27·78	23·30	89·90
October	4·49	31·80	21·70	89·00
Week of sample	0·13	30·55	21·10	85·30
November	..	32·80	16·50	81·10
Week of sample	..	32·22	17·78	83·00
December	1·53	30·76	12·72	79·50
Week of sample	1·53	29·44	16·87	77·70
1934				
January	..	30·27	11·25	90·10
Week of sample	..	30·55	7·22	96·00
February	..	34·44	12·60	74·10
Week of sample	..	33·89	12·80	76·30
March	..	36·11	15·30	68·00
Week of sample	..	37·80	17·80	62·60
April	..	45·90	21.85	73·20
Week of sample	..	37·22	22·20	71 30
May	..	38·05	23·19	74·80
Week of sample	..	38·33	23·30	69·80
June	33·29	30·99	22·80	30·90
Week of sample	3·19	31·11	17·20	83·30
July	36·34	27·80	23·32	87·20
Week of sample	7·16	28·10	23·50	85·00

NITROGEN BALANCE IN BLACK COTTON SOILS IN THE MALWA PLATEAU, II

CHANGES DURING THE HOT WEATHER

BY

YESHWANT D. WAD,

AND

R. K. AURANGABADKAR,

Institute of Plant Industry, Indore, Central India

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(With three text-figures)

INTRODUCTION

Very low yields of seed cotton—about 150 to 500 lbs. an acre—are obtained on the black cotton soils of Malwa in contrast with the higher production—300 to 1,500 lbs. an acre—from Punjab soils. In most of the high-yielding, arid areas cotton is sown in the hot weather much before the rains. When similarly sown in advance of the rains in Malwa local varieties also yielded equally high. [Kubersingh and Wad, 1934, unpublished]. Similar results from early sown crops have been reported from other parts of India [Burt, 1919 ; Hilson, 1928 ; Main, 1908]. Being very well convinced of the depressing influence on yield if sowings are delayed after the rains break, the Malwa cultivator takes good care to finish his sowings rapidly on the beginning of the monsoon. Other crops behave similarly ; maize is preferably sown in the middle of May on garden lands in Malwa. In an experiment at Indore in 1933 the maize varieties, Fitzroy and Imperial Yellow Dent gave acre-yields of 2479 and 2120 lbs. for the hot-weather sown crops and 479 and 256 lbs. for those sown on rains.

Better nitrogen nutrition appeared at least partly responsible for these increments in yields. Before any more efficient system of cultivation could be devised to secure better yields of cotton it seemed essential to secure an accurate estimate of the equilibria and intensities of nitrogen, nitrified or in another form, that may exist in the black cotton soils during the growth periods of an irrigated, hot-weather-sown cotton crop. Direct exposure of the soil surface—wet or dry—to sunlight, and protection of the lower layers from light and to some extent from the effect of wind, are the main features in the environment of a hot-weather crop in its early stages. Under conditions very closely approximating to those in the field, determinations were made of the influence of direct sunlight and temperatures on the nitrification as well as the conservation of nitrogen, both in dry and moist soils, with and without manures. The theory has recently been put forward that nitrification in the tropics occurs mainly through photo-chemical and not biological agencies [Dhar and Rao, 1931]. Sarkaria and Fazal-ud-Din [1934], however, suggest the need of further confirmation before finally accepting this view. The work to be described gives further information on the subject.

MATERIALS AND METHODS

During the summer of 1933 an attempt was made to estimate the effect of the factors given below on the nitrification and conservation of nitrogen in the surface two inches of soil :—

(1) Soil moisture.

(2) Exposure to direct sunlight.

(3) Atmospheric humidity.

(4) Inorganic and organic manures applied at normal field rates.

The parts played by the biological and the recently-suggested photo-chemical agencies during nitrification [Dhar, Bhattacharya and Biswas, 1933 ; Tandon and Dhar, 1934] were also determined.

The technique used was essentially that described in Part I of this series [Wad and Panse, 1933]. Soil, evenly graded by passing through a 2-mm. sieve, was uniformly filled in galvanised iron trays 12 in. × 6 in. and 2 in. deep. The soils used were either unmanured or were mixed thoroughly with compost or ammonium sulphate equivalent to a rate of 17 lbs. of nitrogen per acre/two inches. Half the number of trays were kept in the open in an uncropped field on suitable supports, eighteen inches above ground level and exposed to direct sunlight, side by side with an equal number kept screened from the sun by a corrugated iron sheet roof sloping towards the North and by removable screens to the East or West as needed. Half the number of trays in each set contained dry soil. Sufficient water was added to raise the water content to thirty per cent. The actual daily fluctuations in moisture content ranged between the minima and maxima of fifteen and thirty per cent respectively in covered trays and ten and thirty per cent in those exposed, all losses being replaced daily. The hygroscopic moisture in the original soil was 9·3 per cent and its saturation capacity was 60·0 per cent. Both unmanured and manured soils were included in each group and the position of each tray within a group was interchanged daily at random. The arrangement may be represented thus :

Sun *Shade*

| Watered | Unwatered | | Watered | Unwatered |

Temperatures in the vicinity of each group were recorded daily at 11 A.M. and 3 P.M. (Figs. 1, *a* and *b*). The temperatures in the shade were lower on an average by 5° F. than those in the sun during the hottest period of the day in the warmer spells, the difference being even less on cooler days. The Campbell-Stokes sunshine recorder—universal pattern—was used to record the intensities and duration of sunshine. According to the breadth of markings on the paper the total period of daylight was divided into three portions representing low, medium and high light intensities.

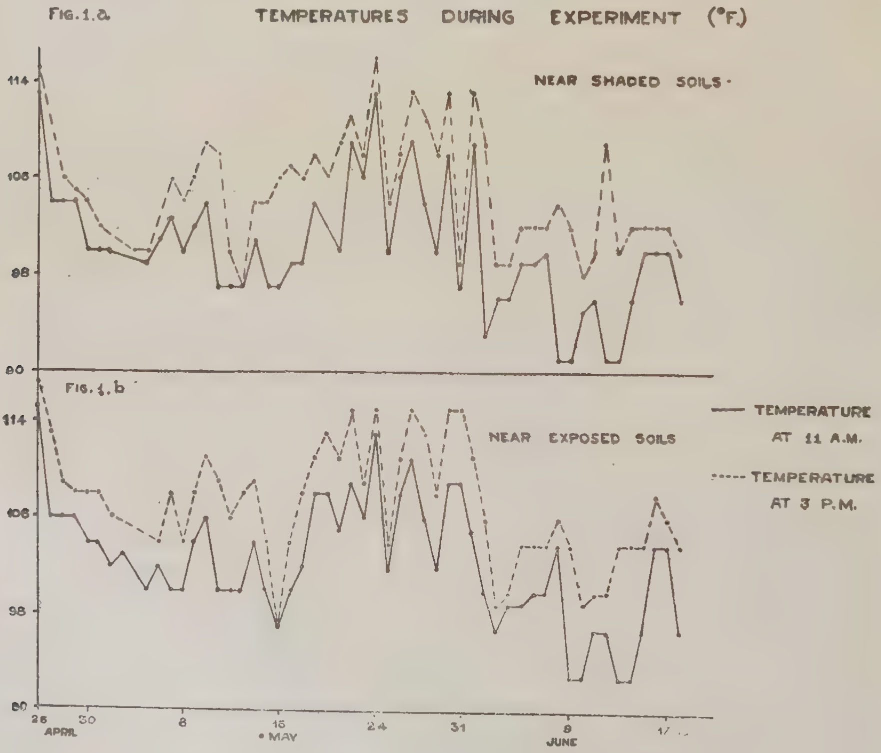

Fig. 1. Temperatures during experiment (°F.)

TABLE I

Hours of sunshine during the period of nitrification

Exposure	Total hours of			
	high intensity	medium intensity	low intensity	Total
19th April—20th May . .	63	116	27	206
21st May—19th June . .	64	92	39	195
Total .	127	208	66	401

In order to estimate the extent of the photo-chemical activity, several 100-grm. lots of soil, dry as well as wetted, with and without manures as in the main experiment, were sterilised in culture flasks, Roux's pattern 8 in. × 5 in. ×2 in. plugged with cotton wool. The dry soils were sterilised at 150° C. for twelve hours and the wetted soils at 120° C. in an autoclave for eight hours. An equal number of flasks of each kind were kept side by side both in light and in darkness at air temperatures, care being taken to interchange the positions of the flasks in each set to ensure uniformity throughout the experiment. The results obtained were again confirmed by another trial with unmanured soil.

The unsterilised sets of the main experiment were started on 19th April and continued up to 19th June 1933. Nitrates were determined by the phenol-di-sulphonic-acid method and total nitrogen by the modified official Kjeldahl method after thirty-one and sixty-one days in the unsterilised set and after thirty-two days in the sterile set. Any chance infections of the sterilised sets during the period of experiment were traced by plating out each sample, and the nitrogen changes in such infected samples were considered separately. All results were statistically evaluated by Fishers' '*t*'-test, P less than 0·05 being taken as the standard for significance. The results are expressed in terms of means of all determinations along with the values of '*t*' for the pairs compared. The value of '*t*' to make each comparison valid on a basis of 19 : 1 is also given for the number of degrees of freedom available. All comparisons made in the text are invariably based on differences which are either significant or insignificant statistically, these terms have therefore been omitted to avoid repetition.

RESULTS AND DISCUSSION

The extent of photo-chemical nitrification in the absence of micro-organisms

The experiments with sterile soils failed to show any significant increases under the influence of sunlight, both in nitrates and total nitrogen (Table II *a*). Wherever subsequent chance infection was found, significant increases occurred directly proportional to its degree (Table II *b*) as shown by the number of colonies on plating.

TABLE II

Nitrogen changes in sterile and chance-infected soils in sunlight and shade (Mgms. of nitrogen per 100 grms. of oven-dry soil)

(*a*) *Sterile samples*

No. of test	Form of nitrogen	Sun	Shade	Sun *vs.* shade t
19th April to 19th May	*With water*			
1.				
a	Nitrate nitrogen	2·38	1·81	1·74
b	Total nitrogen	62·41	62·14	0·45
16th Oct. to 16th Nov.	*With water*			
2.				
a	Nitrate nitrogen	3·59	2·84	0·91
b	Total nitrogen	65·56	65·72	0·77
3.	*Without water*			
a	Nitrate nitrogen	3·08	2·87	0·51
b	Total nitrogen	67·38	66·64	0·33

(*b*) *Infected samples*

No. of test	Form of nitrogen	Infection		Much infected *vs.* less infected
		Much	Less	
19th April to 19th May .				
4.				
a . . .	Nitrate nitrogen .	5·02	3·22	5·40
b . . .	Total nitrogen . .	69·33	64·26	3·43

NOTE :—n=34 for test No. 1 (a & b).
10 for Nos. 2 (a & b) and 3 (a & b).
9 for No. 4a.
8 for No. 4b.
t= 2·042 or more for test No. 1.
2·228 or more for Nos. 2 and 3.
2·268 or more for No. 4a.
2·306 or more for No. 4b.

In this and subsequent tables a comparison is significant only when the value of "*t*" opposite that comparison is greater than the required "*t*" value for them specified at the foot of the table. By a significant comparison is here meant one in which the odds in favour of its being correct are at least nineteen to one.

Incidentally the results emphasize the extreme importance in experiments of this type of making sure, by actual proof, of the absence of subsequent infections, before inferences are drawn. Once infection occurs, organisms multiply very rapidly under favourable conditions. The absolute need of a biological agency to produce nitrogen changes, as well as the complete inability of photo-chemical action in producing such changes are simultaneously proved by these results. At any rate this is true of soils unmanured, treated with ammonium sulphate or with humic compost in doses used in farming practice which are evidently capable of providing the whole range of nitrogenous raw materials susceptible to photo-oxidation.

Temperatures as high as 115° F. did not prevent the existence of micro-organic activity both in the infected samples and the two-inch layers of the unsterilised soils used in the main test. The activity of azotobacter at 46° C. (115°F.) has been known [Green, 1932]. In arid regions even in the hottest season the initial temperatures of over 50° C. continuously existing in moist compost heaps for days together do not seem ever to have prevented the subsequent establishment of biological activities including that of nitrification. The infection evidently has escaped the annihilation to be expected from the death-point determinations made inside a laboratory. The absolute uniformity of conditions so sure in the technique of laboratories may not exist within the large colloidal mass of soils. Otherwise the existence in and isolation of organisms from field or garden soils in extreme climates would have been a difficult task. It is essential to possess correct information regarding the nature of the factors really controlling nitrification in tropical soils, because an efficient adjustment of agricultural practice must be able fully to utilise those factors. The suggested existence of formidable obstacles to biological nitrification [Tandon and Dhar, 1934] can perhaps still be reconciled with the display of its predominance in the tests here described. It is not even necessary to assume the existence of unknown organisms or the survival and activity of familiar species under very drastic conditions. The soil processes are dynamic. The seat of active nitrification need not always coincide with the soil zones having maximum nitrate accumulation, nor are such accumulations necessarily derived from intense activity ; they may result from a persistent but weak activity in a deeper zone.

The rapid decrease in soil temperatures with depth, as indicated at Lyallpur by a fall from 50° C. to 37° C. within 30 cm. only (as mentioned by Tandon and Dhar) makes clear the existence of more favourable temperatures a little lower down. At such depths the supply of oxygen is ample but even if it were not, it must be remembered that the aerobic nodule organisms can retain at least twenty-five per cent of their activity with a concentration of oxygen even as low as 0·5 per cent [Barthel, 1930]. The zone of active nitrification hence may quite easily shift, perhaps with changed intensities, to different depths from season to season according to the nature of the soil. The accumulation at the soil surface of salts, including nitrates, in arid climates [Gardner, Kezer and Ward, 1934] or during dry seasons, is a consequence. Under such conditions a wide range exists for the transport of salts to the surface (through the upward movement of moisture from the subsoil to be accumulated there on drying). The coincidence of such accumulations with hot and dry seasons is hence as easy to understand as their downward movement by leaching in wet weather. Even in extremely rigorous climates biological nitrification can thus be carried on safely beyond the reach of light without any danger of the organisms being poisoned by formaldehyde liable to be produced photo-chemically.

Instead of being directly dependent upon the production of nitrates, the physical improvement of soil by exposure during hot seasons may be due simply to the increased stability of the structure of its aggregates—a direct result of the irreversibility produced in the cementing material of the humus-clay complex when the former is coagulated by calcium [Sokolovsky, 1930]. Such a granular structure controls the efficiency of the water, air and biological regime in the soil. The high exchange capacity [McGeorge, 1930] of the argillo-humus fraction when suitably reinforced with calcium enables the soil to resist better the inevitable deterioration of its structure—due to the disturbance of the equilibrium between soil-colloids and the absorbed calcium [Sokolovsky, 1930] which must be caused by crop-growth and biological activities like nitrification. In the absence of stable soil structure even " nitre spots " may be barren. The phenomenon of nitrification even in the tropics can thus, after all, still be the same as elsewhere.

NITRIFICATION

(a) *Watered soils*

Nitrogen changes in watered soils during periods of thirty-one and sixty-one days are given in Tables III and IV (*a* and *b*). Table V gives the accumulations and percentages of nitrified nitrogen in sunlight as well as in shade.

TABLE III

Nitrogen changes in watered soils during 31 days

(*a*) *On oven-dry basis*

Treatment	Nitrate accumulation (Mgms. N per100 grms. of soil)		Nitrified N on total (Average of percentages)		Total nitrogen (Mgms. N. per 100 grms. of soil)			Average of per cent losses after 31 days	
					At start	After 31 days			
	Sun	Shade	Sun	Shade		Sun	Shade	Sun	Shade
Compost (A)	5·81	4·45	7·11	5·45	81·74	76·79	74·32	5·94	9·06
Amm. Sulph. (B) . .	5·50	4·55	6·92	5·72	79·53	77·76	75·54	3·07	5·20
Control (C)	5·48	3·92	7·88	5·55	70·68	58·68	59·99	16·98	15·24

(*b*) *Comparisons* (*values of* t)

Treatment	Sun *vs.* shade			Comparisons	Sun			Shade		
	Nitrate accumulation	Per cent nitrified N	Nitrogen losses		Nitrate accumulation	Per cent nitrified N	Nitrogen losses	Nitrate accumulation	Per cent nitrified N	Nitrogen losses
A	5·24	5·19	2·31	A *vs.* B	1·22	0·59	1·97	0·48	1·02	2·22
B	4·52	4·53	1·53	A *vs.* C	0·90	1·62	8·21	2·02	0·30	3·45
C	4·40	4·80	1·30	*B vs.* C	0·06	2·18	12·20	3·07	0·51	6·04

NOTE :—$n = 14$ throughout, $\therefore t = 2{\cdot}145$,

TABLE IV

Nitrogen changes in watered soils during 61 days

(a) On oven-dry basis

Treatment	Nitrate accumulation (Mgms. N per 100 grms. of soil)		Nitrified N on total (Average of percentages)		Total nitrogen (Mgms. N per 100 grms. of soil)			Average per cent losses after 61 days	
					At start	After 61 days			
	Sun	Shade	Sun	Shade		Sun	Shade	Sun	Shade
Compost (A) . . .	7·15	5·61	8·75	6·86	81·74	72·14	75·93	10·83	7·17
Amm. Sulph. (B) . .	6·56	5·24	8·25	6·59	79·53	74·22	73·48	6·66	8·06
Control (C) . . .	4·56	4·29	6·45	5·92	70·68	57·38	58·16	18·81	18·07

(b) Comparisons (values of t)

Treatment	Sun *vs.* shade			Comparisons	Sun			Shade			1st *vs.* 2nd period		
	Nitrate accumulation	Per cent nitrified N	Nitrogen losses		Nitrate accumulation	Per cent nitrified N	Nitrogen losses	Nitrate accumulation	Per cent nitrified N	Nitrogen losses	Treatment	Sun	Shade
A	9·34	9·45	2·72	A *vs.* B.	3·69	2·56	3·03	2·85	1·54	0·75	A	3·02	1·34
B	11·00	10·38	1·14	A *vs.* C.	14·39	9·79	6·03	9·43	2·99	7·81	B	3·02	1·97
C	1·68	1·54	0·54	B *vs.* C.	13·34	9·00	12·06	7·31	2·06	6·37	C	1·98	1·66

Note.—$n=14$ throughout ∴ $t=2\cdot145$.

TABLE V

Percentage changes in and net values of nitrate accumulations and intensities of nitrification in each period in watered soils

Treatment	Accumulations—Mgms. N per 100 grms. of soil								Intensities—percentages of nitrate N on total nitrogen							
	Percent increase in sun over shade		Sun			Shade			Percent increase in sun over shade		Sun			Shade		
	During		During		Per cent decrease during 2nd period	During		Per cent decrease during 2nd period	During		During		per cent. decrease during 2nd period	During		Per cent decrease during 2nd period
	1st period	2nd period	1st period	2nd period		1st period	2nd period		1st period	2nd period	1st period	2nd period		1st period	2nd period	
Compost	30·56	15·52	5·81	1·34	76·60	4·45	1·16	73·92	30·46	16·31	7·11	1·64	76·93	5·45	1·41	74·13
Amm. Sulph.	20·87	65·12	5·50	1·06	80·72	4·55	0·69	84·84	20·98	52·84	6·92	1·33	80·60	5·72	0·87	84·78
Control.	39·79	348·60	5·48	Loss 0·92	116·80	3·92	0·37	90·55	41·99	486·50	7·88	Loss 1·43	118·10	5·55	0·37	93·33

The favourable influence of exposure to sunlight was always visible with the only exception of untreated soils during the second period. The untreated soils received the greatest stimulus by light during the first period inspite of the absence of added easily oxidisable nitrogen. Ammonium sulphate though readily oxidisable fell behind compost which topped the list. During the second period there was a general drop in activity resulting in actual depression in untreated soils. It may be pointed out that there was no dearth of total nitrogen, though some was lost, but these losses were significant only with treatments in sunlight. Also treated soils suffered from depression in activity less than controls, while compost resisted it better than ammonium sulphate.

Evidently something other than sunlight or the micro-organisms or the nitrifiable material appears to be the controlling factor. Compost has exploited this to the best advantage, thus indicating that organic matter of a certain type was the decisive element. The nitrifying activity is lowered when this organic matter is not replenished. It may be that the organic carbon in the argillo-humus fraction is adversely affected by the very process of nitrification and the structure of the soil aggregates deteriorates.

The most efficient recovery of nitrogen in nitrified form from soils seems to be possible only when the process starts at a high intensity before the unfavourable phase gets the upper hand. Otherwise as time goes on the soil efficiency is reduced, probably due to its deterioration and the chances of recovery become smaller and smaller perhaps because the waste of nitrogen is increased by its being used up in other reactions going on side by side. This is clearly illustrated by the greater depression of activity under shade as time advances, in comparison with that in sunlight which stimulates the nitrification. This stimulus brings about the deterioration phase quickly in untreated soil but ammonium sulphate and, to a greater extent, compost retard its appearance and much more in light than in shade.

This point and the similarity in behaviour of ammonium sulphate and compost—two substances widely differing in their properties—requires careful investigation. The oxidation of ammonium sulphate in soils does not seem to be an independent chemical reaction. On the assumption of the intervention of the agency of micro-organisms there seems to be an intimate association of oxidation of ammonium sulphate with a source of energy available in close contact with it. The similarity referred to suggests humus-carbon as the source of energy. The quicker fall in activity of untreated soils than of those ammonium sulphate-treated which had no additions of organic matter and yet had to deal with larger quantities of nitrogen indicates that ammonium sulphate utilises soil humus more efficiently unless it provides itself with some other source of energy. A closer study of the mechanism by which ammonium sulphate is oxidised in soils is likely to give information useful for practical soil management.

(*b*) *Unwatered soils*

Results are given in Tables VI and VII, (*a* and *b*) and VIII.

TABLE VI

Nitrogen changes in unwatered soils during 31 days

(*a*) *On oven-dry basis*

Treatment	Nitrate accumulation (Mgms. N per 100 grms. of soil)		Nitrified N on total (Average of percentages)		Total nitrogen (Mgms. N per 100 grms. of soil)			Average of per cent losses after 31 days	
					At start	After 31 days			
	Sun	Shade	Sun	Shade		Sun	Shade	Sun	Shade
Compost (A) . . .	3·20	3·40	3·91	4·27	81·74	74·55	75·53	8·80	7·41
Amm. Sulph. (B) .	3·13	3·18	3·75	3·99	79·53	72·80	74·94	8·83	6·41
Control (C) . . .	2·80	3·08	4·50	4·36	70·68	62·64	60·61	11·15	10·39

(*b*) *Comparisons* (*values of* t)

Treatment	Sun *vs.* shade			Sun				Shade		
	Nitrate accumulation	Per cent nitrified N	Nitrogen losses	Comparisons	Nitrate accumulation	Per cent nitrified N	Nitrogen losses	Nitrate accumulation	Per cent nitrified N	Nitrogen losses
A	1.34	2.00	0.78	A *vs.* B	2.80	1.46	0.01	1.00	1.12	0.61
B	0.16	1.17	1.38	A *vs.* C	6.15	2.41	1.43	1.83	0.05	1.73
C	2.80	0.55	0.48	B *vs.* C	5.50	3.26	1.43	0.56	1.57	1.79

Note.—$n=14$ throughout ∴ $t=2.145$

TABLE VII

Nitrogen changes in unwatered soils during 61 days

(*a*) *On oven-dry basis*

Treatment	Nitrate accumulation (mgms. N per 100 grms. of soil)		Nitrified N on total (average of percentages)		Total nitrogen (Mgms. N per 100 grms. of soil)			Average of per cent losses after 61 days	
					At start	After 61 days			
	Sun	Shade	Sun	Shade		Sun	Shade	Sun	Shade
Compost (A) . . .	3·57	3·10	4·37	3·72	81·74	74·55	72·09	8·62	11·81
Amm. Sulph. (B) . .	3·43	2·72	4·31	3·39	79·53	74·03	75·50	7·07	8·38
Control (C) . . .	2·94	3·02	4·18	4·27	70·68	60·61	59·39	11·38	14·24

(*b*) *Comparisons (values of* t*)*

Treatment	Sun *vs.* shade			Sun				Shade			1st *vs.* 2nd period		
	Nitrate accumulation	Per cent nitrified N	Nitrogen losses	Comparisons	Nitrate accumulation	Per cent nitrified N	Nitrogen losses	Nitrate accumulation	Per cent nitrified N	Nitrogen losses	Treatment	Sun	Shade
A	5·52	4·64	3·09	A *vs.* B	2·33	0·86	1·08	1·95	1·83	1·99	A	0·12	3·35
B	3·94	4·61	0·69	A *vs.* C	7·00	1·73	2·51	0·73	3·14	1·53	B	0·98	1·03
C	0·74	0·60	1·79	B *vs.* C	5·16	1·08	2·95	1·62	5·78	0·82	C	0·19	2·05

Note.—$n=14$ throughout ∴ $t=2\cdot145$.

TABLE VIII

Percentage changes in and net values of nitrate accumulations and intensities of nitrification in each period in unwatered soils

Treatment	Accumulations (Mgms. N per 100 grms. of soil)						Intensities (Percentages of nitrified N on total)					
	Sun			Shade			Sun			Shade		
	During		Per cent decrease during 2nd period	During		Per cent decrease during 2nd period	During		Per cent decrease during 2nd period	During		Per cent decrease during 2nd period.
	1st period	2nd period		1st period	2nd period		1st period	2nd period		1st period	2nd period	
Compost . .	3·20	0·37	88·45	3·40	Loss 0·30	108·8	3·91	0·46	88·22	4·27	Loss 0·55	112·9
Amm. Sulph.	3·13	0·30	90·42	3·18	Loss 0·46	114·5	3·75	0·56	85·07	3·99	Loss 0·60	115·0
Control .	2·80	0·14	94·99	3·08	Loss 0·06	102·0	4·50	0·32	107·1	4·36	Loss 0·09	102·1

(c) *Watered and unwatered soils*

The accumulation of nitrates and the intensity of nitrification is higher in watered soils under all conditions than in dry soils (Tables IX and X *a, b, c*).

In sunlight, watered soils did not show differences due to treatments in the first period while in dry soils there was a gradation, compost standing highest followed by ammonium sulphate, control being last.

In shade in the same period ammonium sulphate topped the list in watered soils but was not significantly different from compost, while in unwatered soils there was no difference due to treatments.

During the second period both in sunlight and in shade the watered soil showed a gradation—compost standing first followed by ammonium sulphate and control. In dry soils during the same period the gradation existed only in sunlight but not in shade.

These differences in behaviour of treatments in presence and absence of water does not seem to be due simply to general differences in water contents. It will be seen from Table XI (*a* and *b*) that the moisture contents of unwatered soils were higher during the second period than in the first with the exception of control in sunlight, which did not alter. Between treatments, under all conditions, untreated soils retained more water than the treated ones. Ammonium sulphate showed the least water content, except during the second period (in both sunlight and shade) when, though numerically consistently lower, its water-content did not significantly differ from that with compost.

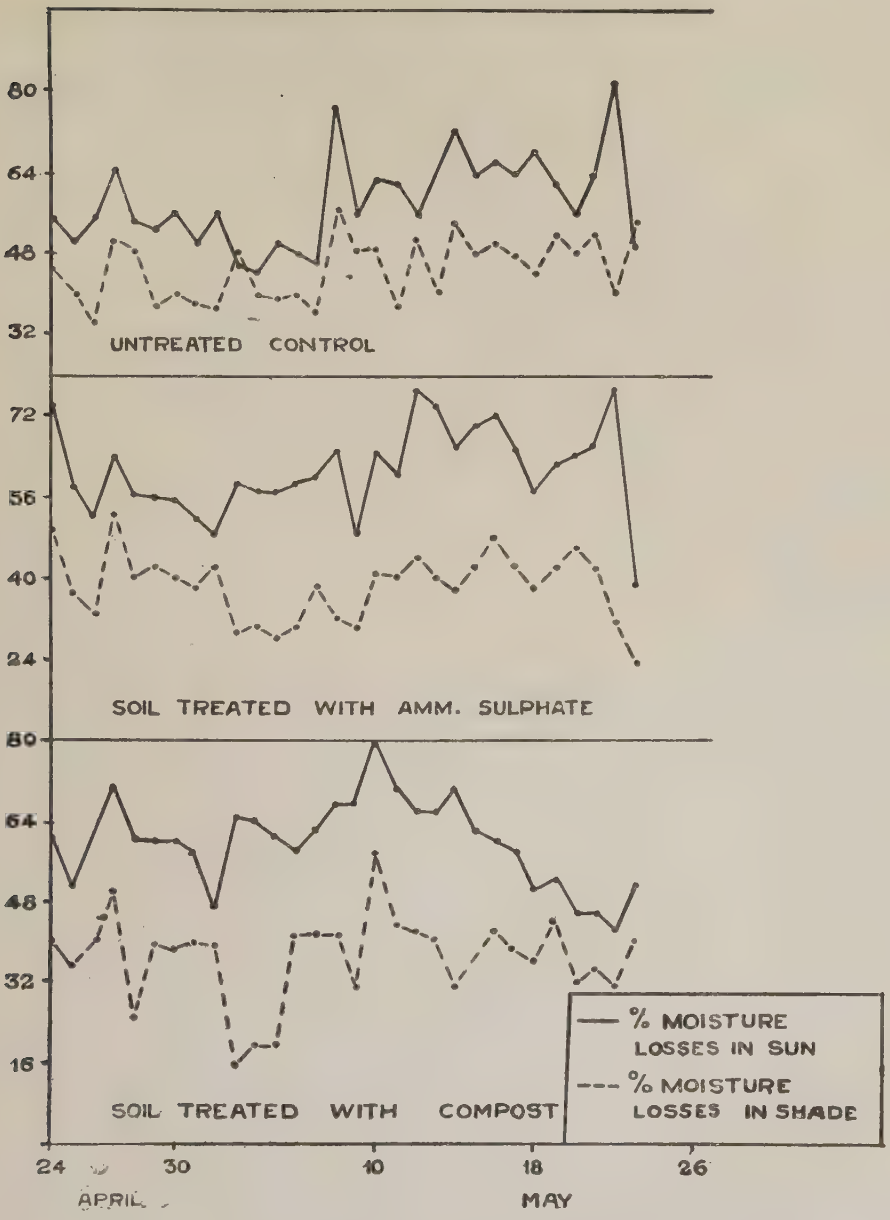

Fig. 2. Daily per cent losses of moisture from experimental soils.

The influence of time on nitrate accumulation and the intensity of nitrification in dry soils, both under sunlight and in shade is compared in Table XII (*a*, *b*, *c*).

In sunlight, in spite of the identical moisture contents of the untreated soils in both periods, these accumulated more nitrates in the second period than the first.

TABLE IX

Nitrogen changes in watered and unwatered soils during 31 days

On oven-dry basis

(*a*) *In sunlight*

Treatment	Accumulations (mgms. of N per 100 grms. of soil)		Nitrified N on total (average of percentages)		Total nitrogen				
					Mgms. N per 100 grms. of soil			Average of per cent losses after 31 days	
					At start	After 31 days			
	Watered	Unwatered	Watered	Unwatered		Watered	Unwatered	Watered	Unwatered
Compost . .	5·81	3·20	7·11	3·91	81·74	76·79	74·55	5·94	8·80
Amm. sulph. .	5·50	3·13	6·92	3·75	79·53	77·76	72·80	3·07	8·83
Control . .	5·48	2·80	7·88	4·50	70·68	58·68	62·64	16·98	11·15

(*b*) *In shade*

Treatment	Accumulations (mgms. of N per 100 grms. of soil)		Nitrified N on total (average of percentages)		Total nitrogen				
					Mgms. N per 100 grms. of soil			Average of per cent losses after 31 days	
					At start	After 31 days			
	Watered	Unwatered	Watered	Unwatered		Watered	Unwatered	Watered	Unwatered
Compost . .	4·45	3·40	5·45	4·27	81·74	74·32	75·53	9·06	7·41
Amm. sulph .	4·55	3·18	5·72	3·99	79·53	75·54	74·94	5·20	6·41
Control . .	3·92	3·08	5·55	4·36	70·68	59·99	60·61	15·24	10·39

TABLE IX—*contd.*

(*c*) *Comparisons—watered* vs. *unwatered soils* (*values of* t)

Treatment	Sun			Shade		
	Nitrate accumulation	Per cent nitrified N	Nitrogen losses	Nitrate accumulation	Per cent nitrified N	Nitrogen losses
Compost	12·72	11·43	1·62	4·77	4·92	0·92
Amm. sulph..	15·80	15·85	3·62	6·23	6·29	0·77
Control	8·65	7·43	4·98	4·00	2·90	2·84

Note.—$n=14$ throughout, ∴ $t=2\cdot145$.

TABLE X

Nitrogen changes in watered and unwatered soils during 61 days

On oven-dry basis

(*a*) *In sunlight*

Treatment	Accumulations (mgms. of N per 100 grms. of soil)		Nitrified N on total (Average of percentages)		Total nitrogen				
					Mgms. N per 100 gms. of soil			Average of per cent losses after 61 days	
					At start	After 61 days			
	Watered	Unwatered	Watered	Unwatered		Watered	Unwatered	Watered	Unwatered
Compost . .	7·15	3·57	8·75	4·37	81·74	72·14	74·55	10·83	8·62
Amm. sulphate .	6·56	3·43	8·25	4·31	79·53	74·22	74·03	6·66	7·07
Control . .	4·56	2·94	6·45	4·18	70·68	57·38	60·61	18·81	11·38
(*b*) *In shade*									
Compost . .	5·61	3·10	6·86	3·72	81·74	75·93	72·09	7·17	11·81
Amm. sulphate .	5·24	2·72	6·59	3·39	79·53	73·48	75·50	8·06	8·38
Control . .	4·29	3·02	5·92	4·27	70·68	58·16	59·38	18·07	14·24

TABLE X—*contd.*

(c) *Comparisons—watered* vs. *unwatered soils (values of* t)

Treatment	Sun			Shade		
	Nitrate accumulation	Per cent nitrified N	Nitrogen losses	Nitrate accumulation	Per cent nitrified N	Nitrogen losses
Compost	27·44	26·54	1·61	19·31	16·97	4·76
Amm. sulphate	31·30	32·84	2·87	12·92	15·24	0·18
Control	10·80	11·08	7·32	10·58	5·16	3·17

Note.—$n=14$ throughout, $\therefore t=2·145$.

TABLE XI

(a) *Average of percentage moistures in unwatered soils at the end of different periods*

Treatment	1st period		2nd period	
	Sun	Shade	Sun	Shade
Compost (A).	6·74	6·81	7·13	7·23
Amm. sulph. (B)	6·14	6·40	7·01	7·14
Control (C)	7·38	7·32	7·45	7·77

(b) Comparisons (values of t*)*

Treatment	Sun *vs.* shade		Comparisons	Sun		Shade		Treatment	1st *vs.* 2nd period	
	1st period	2nd period		1st period	2nd period	1st period	2nd period		Sun	Shade
A	0·47	1·18	A *vs.* B .	3·43	1·20	3·42	1·80	A	2·44	6·00
B	1·73	1·86	A *vs.* C .	4·00	2·91	4·25	4·91	B	7·25	6·17
C	0·46	2·46	B *vs.* C .	9·54	3·40	6·13	5·95	C	0·64	3·00

Note.—$n=14$ throughout, $\therefore t=2\cdot145$.

TABLE XII

Nitrogen changes in unwatered soils as influenced by the duration of time (on oven-dry basis)

(a) In sunlight

Treatment	Accumulations (mgms. of N per 100 gms. of soil)		Nitrified N on total (average of percentages)		Total nitrogen				
					Mgms. N per 100 grms. of soil			Average of per cent losses at the end of	
					At start	After			
	1st period	2nd period	1st period	2nd period		1st period	2nd period	1st period	2nd period
Compost . .	3·20	3·57	3·91	4·37	81·74	74·55	74·55	8·80	8·62
Amm. sulph. .	3·13	3·43	3·75	4·31	79·53	72·80	74·03	8·83	7·07
Control . .	2·80	2·94	4·50	4·18	70·68	62·64	60·61	11·15	11·38

TABLE XII—*contd.*

(*b*) *In shade*

Compost	3·40	3·10	4·27	3·72	81·74	75·53	72·09	7·41	11·81
Amm. sulph	3·18	2·72	3·99	3·39	79·53	74·94	75·50	6·41	8·38
Control	3·08	3·02	4·36	4·27	70·68	60·61	59·38	10·39	14·24

(*c*) *Comparisons—1st and 2nd period* (*values of* t)

Treatment	Sun			Shade		
	Nitrate accumulation	Per cent nitrified N	Nitrogen losses	Nitrate accumulation	Per cent nitrified N	Nitrogen losses
Compost	6·75	0·12	0·12	1·67	2·68	3·35
Amm. sulph.	6·00	6·79	0·98	2·00	2·22	1·03
Control	2·79	1·61	0·19	0·55	0·56	2·05

Note.—n=14 throughout, ∴ t =2·145.

In shade both treated and untreated soils showed no differences in accumulation between the two periods though the moisture contents were higher in the second period.

When intensities of nitrification are compared, compost in sunlight and untreated soils in shade do not show these differences to be expected from their increased water-contents in the second period. In all other cases nitrification—both accumulation and intensity—increases with the water-content of soils.

Though the accumulation in dry soils was less than in moist, its relative rate of decrease with time was much higher (Tables VI *a* and VIII *a*) except with untreated soils exposed to sunlight. None of these peculiarities in the behaviour of dry soils seems to bear any relation to the degree of nitrogen loss sustained by the soils (Tables VI *c* and VII *c*).

Temperature variations also do not seem to be connected in any way, those between the periods showing no consistency (Fig. 1 *a*, *b*). The humidities, however were consistently higher (Fig. 3) in the second period.

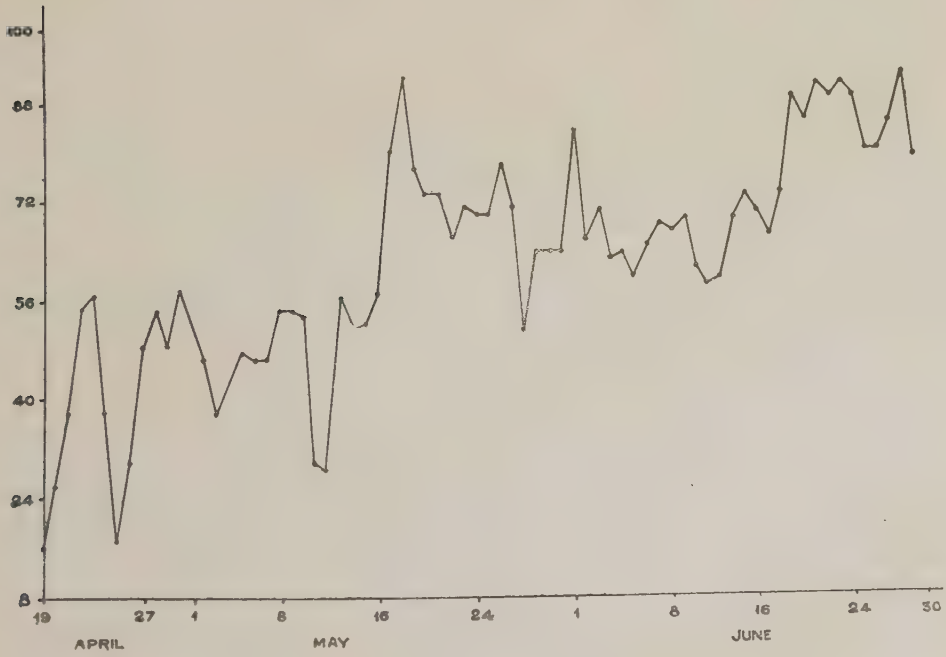

Fig. 3. Relative per cent humidities during the experimental period.

Perhaps the humidities in the air surrounding the regions of activity are of even greater importance than the actual moisture content of unwatered soils. The watered soils can obviously maintain a highly humid atmosphere even when exposed to the sun. The unwatered treated soils, which show lower water-content than the control (and thus indicate a greater tendency to permit its evaporation) will also enable a similarly high humidity to exist around the region of nitrifying activity. The higher water-content of untreated soils seems to be less useful for this purpose, perhaps because it is less easily vaporised, being bound by the colloids to a greater extent. A possible explanation of the influence of humidity on nitrification is, that it facilitates the maintenance of a steady film of available water as a medium for nitrification, thus explaining the presence of nitrifying activity even in unwatered soils. Evidently at the surfaces of activity a moderate but sufficiently thick film of moisture must have existed. Lebedev [1930] has shown that at all moisture contents exceeding the hygroscopic amount, cent per cent humidities exist in the soil air. The maintenance of a permanent film of moisture on the colloid surfaces as small localised patches, seems thus quite possible. The limited extent of such a film is probably closely connected with the rapid decrease in nitrifying activity. It is perhaps also possible that nitrification can occur only on a certain type of clay surface which rapidly becomes unfit for the process through its own nitrifying activities. It may be that the moisture film on the colloidal clay particle permits nitrification to go on at a rate far exceeding that of the recuperative changes within that particle which retard the depression in nitrifying activity.

The comparison of exposed and covered, watered and unwatered soils lends some support to this view. With copious water supply and the stimulation associated with sunlight the deterioration was greatest but under shade it was less. With restricted water, however, the water-content which is higher in shade becomes the limiting factor, the deterioration directly varying with it (Table XI *a*, *b*). The protective influence of additional moisture in the watered soils under shade is perhaps due to the water being to a certain extent available for that process within the clay particle which retards the deterioration directly and simultaneously resulting from the nitrifying activity.

TEMPERATURE AND NITROGEN CHANGES

Black cotton soil treated with ammonium sulphate equivalent to seventeen lbs. of nitrogen per acre/two inches, was kept in the shade for two months in two sets, one at an average temperature of 83·5° F. and the other at 108° F. The results are given in Table XIII.

TABLE XIII

Changes in nitrification due to temperature

	At high temperature	At low temperature	n	P	Significances
After 30 days					
Nitrate N . . .	4·55	2·20	7	$<0·01$	Highly significant.
Total N . . .	77·75	81·74	7	$>0·05$	Insignificant.
After 60 days					
Nitrate N . . .	5·24	2·30	7	$<0·01$	Highly significant.
Total N . . .	74·22	89·84	7	$>0·05$	Insignificant.

The acceleration of nitrification due to high temperatures has been recorded by Sahasrabuddhe and Kanitkar [1932]. The favourable influence of sunlight mentioned before (Tables III *a* and IV *a*), though very appreciable, falls much below that of higher temperature. Results by Fraps and Sterges [1935] show clearly that light actually inhibits nitrification, hence the greater nitrification found in the Indore experiments in trays exposed to sunlight must have been due to the higher temperature of the interior unexposed mass, the soil in the trays not having stirred to expose fresh surfaces to the inhibiting effect. As temperatures operate upon a far greater depth than light can penetrate, they must exert a far greater influence on crop-nutrition than could light. An estimate of the influence of climate, and season within the climate, on crop-development should include a relative measure of the influences of both. The practical possibility of nitrifying activity existing at high temperatures is evident from these results also.

LOSSES AND GAINS OF NITROGEN

Tables III, IV, VI and VII give losses and gains on initial total nitrogen at the end of each period.

(*a*) *Watered soils*

1st period.—Under the influence of sunlight compost treatment lost less than in shade but others showed no difference. Control lost under both light and shade much more than treated soils which showed difference only in shade, ammonium sulphate losing less than compost.

2nd period.—Compost lost more in the sun than in shade ; others showed no difference. Control lost more heavily than the treatments both in sun and shade. Only in the sun did compost show a greater loss than ammonium sulphate.

In sunlight both treatments showed a greater total loss at the end of the second period than the first. Other differences were not significant.

Table XIV *a* gives the percentages of actual losses or gains incurred during each period as well as the changes in the degree of loss expressed as the percentage increase or decrease over the loss in the first period.

TABLE XIV

Percentage losses in total nitrogen during each period in sunlight and shade with their decreases or increases between the two periods. (These losses are calculated on total nitrogen existing at the beginning of each period.)

Treatment	Sun			Shade		
	During		Per cent increase or decrease of losses on 1st period	During		Per cent increase or decrease of losses on 1st period
	1st period	2nd period		1st period	2nd period	
			(*a*) *Watered soils*			
Compost . .	6·06	6·06	0·00	9·08	Gain 2·10	Decrease 123·40
Am. sulph. .	2·23	4·54	Increase 103·6	5·02	2·06	Decrease 47·21
Control . .	16·97	2·22	Decrease 86·92	15·12	3·12	Decrease 85·96
			(*b*) *Unwatered soils*			
Compost . .	8·80	0·00	Decrease 100·00	7·60	4·56	Decrease 26·84
Am. sulph. .	8·46	Gain 1·69	Decrease 119·90	5·77	Gain 0·75	Decrease 113·00
Control . .	11·38	3·24	Decrease 71·53	14·25	2·03	Decrease 92.23

These figures are calculated from the means and do not represent the averages of individually-calculated results as do those in other tables where statistically examined data are included. The conclusions, however, are based on wide differences and hence are likely to be reliable.

With compost the rate of loss in sunlight is the same in both periods. Under shade there is an actual gain in the second period though the rate of loss is higher in shade than in sun during the first period. During the second period losses with ammonium sulphate increased in the sun and decreased in the shade. In the first period the order was reversed, so resembling compost. The losses in controls in the second period decreased but were practically alike in the first period and much higher than in the treatments. During the second period and in shade the controls lost more than the treatments but in the sun this was reversed. The losses with compost were mid-way between those of control and ammonium sulphate for all conditions except the second period in shade.

It is remarkable that under all conditions a period of low rate of loss is followed by one of a higher rate and *vice versa.* Compost showed a steady rate of loss under unfavourable conditions and could actually achieve a net gain in favourable conditions, while under similar environment ammonium sulphate and control showed greater fluctuation in the rates of their losses, and no gains.

This seems to lend further support to the view expressed before that two processes—one destructive and the other constructive—always go on in the soil simultaneously with the changes in its nitrogen. Organic matter, if supplied, retards degeneration and promotes recuperation. The dependence of soil efficiency on the existence of organic matter of a certain type is strongly indicated; further, in the very process of nitrogen change such organic matter is utilized.

(*b*) *Unwatered soils*

1st period.—Sunlight, shade or treatments made no difference to losses of nitrogen.

2nd period.—Compost showed a greater loss in shade, others did not show any difference. Between treatments in sunlight, control showed a greater loss in this period. Comparing the two periods, there were no differences in sunlight but in shade compost and control lost more during the second than the first period. With ammonium sulphate there was no change.

Table XIV *b* gives the percentages of actual losses or gains incurred during each period as well as the relative changes in the degree of loss expressed as the percentage increase or decrease over the loss in the first period.

Compost in the second period showed decrease in the rate of loss which decrease was intensified in sunlight. The rate of loss was slightly higher in sunlight than in shade during the first period.

Ammonium sulphate in the second period showed a similar, but more pronounced series of changes, almost alike in light and shade, so that actual gains were registered.

Control in the second period showed decreases in rate of loss both in light and shade but in the first period more so in shade, where its rate of loss was also higher than in sunlight. Control showed the highest initial rates of loss everywhere, compost coming next and ammonium sulphate being nearly equal to compost in sunlight but lower in shade.

The steadying influence of compost is again noticeable. The succession of higher rates of losses by lower ones or by gains is also apparent. Ammonium sulphate shows, however, a greater efficiency than compost in contrast with its behaviour in watered soils. This, as suggested before, seems to indicate its ability to utilise soil carbon more efficiently and perhaps also the need of sufficient moisture for the operation of compost in helping recuperation.

(c) *Watered soils compared with unwatered*

Tables IX and X show the comparisons.

The losses were greater with unwatered soils treated with compost in shade during the second period ; other conditions made no difference.

Ammonium sulphate in unwatered soils showed higher losses in sunlight in both periods. There were no other differences.

Untreated soils, however, showed everywhere greater losses in presence of water. Thus, under conditions of greater activity (watered soils) the treatments led to a more efficient nitrogen economy. The influence of compost is obviously through its organic matter, but that of ammonium sulphate again requires explanation. Whether it is due to more efficient use of existing carbon or to other causes it is hard to say in the absence of determinations of carbon contents at different stages.

A further point to be noted is the apparently general co-existence of high nitrification with high losses and of low nitrification with low losses. In subsequent monsoon experiments, however, (yet to be reported) the reverse was found. Even in the present experiments watered soils in sunlight, treated with ammonium sulphate lost more in the second period when accumulation of nitrates had fallen. It also happened that atmospheric humidities were high whenever losses were low and when gains were noticed. The changes in the nature of the medium (treated and untreated soils) seem to need better understanding before the differences observed can be satisfactorily explained.

Further, it appears that the ease with which soils lose water seems also to affect nitrogen losses. For instance, the daily moisture loss (from watered soils) increased, by exposure to sunlight, by 27·2, 22·5 and 12·1 per cent for compost, ammonium sulphate and no treatment respectively. The mean percentage losses in total nitrogen in sun-exposed soils decreased by 3·12 and 2·13 for compost and ammonium sulphate but increased by 1·74 for no treatment. With decreased mobility of water the tendency to lose nitrogen seems to have increased. Perhaps a difference in texture is operating.

TABLE XV

Treatment	Differences in watered soils between exposed and shaded samples during the first period	
	Daily moisture losses	Mean percentage of losses in total nitrogen
	Per cent	
Compost	+27·18	Decreased by 3·12
Amm. sulph.	+22·46	Decreased by 2·13
Control	+12·05	Increased by 1·74

DAILY PERCENTAGE LOSSES IN MOISTURE FROM WATERED SOILS

TABLE XVI

(*a*) *Average of percentage moisture losses and the differences in losses in watered soils in sunlight and shade* (*on fresh basis*).

Treatment	Average of daily percentage moisture losses				Differences in per cent moisture losses in sun and shade during 1st period
	During 1st period		During 2nd period		
	Sun	Shade	Sun	Shade	
Compost (A)	63·7	36·5	49·2	57·1	27·2
Amm. sulph. (B)	58·2	36·3	58·0	50·8	22·5
Control (C)	56·8	44.7	51·2	52·0	12·1

(*b*) *Comparisons* (*values of* t)

Treatment	Sun *vs.* shade		Comparisons	Sun		Shade		Differences in per cent moisture losses in sun and shade during 1st period
	1st period	2nd period		1st period	2nd period	1st period	2nd period	
A . . .	8·09	1·45	A *vs.* B	1·44	1·41	0·05	1·07	1·03
B . . .	6·54	0·93	A *vs.* C .	1·92	0·39	2·33	1·34	3·03
C . . .	3·27	0·23	B *vs.* C .	0·34	1·41	3·05	0·21	2·40

Note.—n for comparisons during 1st period=26, ∴ t=2·056.
n for comparisons during 2nd period=16, ∴ t=2·120.

During the first period the differences in daily moisture loss in exposed samples were not significant, while in shade only the untreated soils showed higher losses. This indicates better preservation of moisture by treated soils in shade and also that when exposed they are at least not worse than control in this respect.

In treated soils whether in sun or shade moisture losses did not differ but were greater than in control; treatments hence induced a greater mobility of water. The better conservation, coupled with this greater mobility is an index of improved texture. The greater stability of water content in manured soils under natural field conditions may be explained as being the direct result of the cessation of the upward rise of the more mobile water much earlier than in unmanured soils, owing to the complete drying out of the surface due to the more open texture, further losses then ceasing. The similarity of both compost and ammonium sulphate in these respects indicates that in the very heavy intractable black soils, open texture, no matter how produced, is essential to maintain steady moisture (with its dissolved material) coupled with easy mobility of air and water, in spite of the usual weather fluctuations. The importance of this to crop-development is obvious.

During the next period the differences were not statistically significant anywhere. This is due to the high error of the treated samples in most cases. An important point however is noticeable. High humidities prevailed in this period (Fig. 3). The losses with compost-treated soils were consistently the highest (numerically) in shade but lowest when exposed. Hence the paradox that soil moisture tends to be reduced when surface evaporation is low and to be preserved when it is high. The great sensitiveness in achieving this adjustment is indicated by the high errors. The daily figures for losses fluctuated in as varied a manner as the weather changes, reducing their uniformity to a minimum. The capacity of the compost treatment to minimise the chances both of deficiencies as well as excesses of soil water is vividly brought out and its practical value needs no mention. The rôle of a loose mulch in moisture regulation seems to be capable of a similar explanation. Moisture will be retained, lost or kept constant according to atmospheric environment.

The behaviour of ammonium sulphate was just the reverse of that of compost though the sensitiveness as indicated by the magnitude of error is of the same order. The losses were low under shade and high when exposed. A tendency to accumulate water with low evaporation and to allow it to dry out when it is high is certainly not optimum for crop-development. This difference in the openness produced by minerals and that resulting from organic matter is of considerable practical and theoretical significance. The low nitrification of ammonium sulphate in spite of better nitrogen conservation in the open as compared with that of compost illustrates the point.

Moisture contents of unwatered soils at the end of each period (*Table XI a, b*)

In the first period when humidities were low, exposure did not make any difference to water content. Under the high humidities prevailing in the next period, however, the untreated soils showed a higher moisture in shade, so contrasting with the treated soils. Under shade all soils contained in this period more moisture than during the first dry period. These findings indicate a slow accumulation of moisture in the lower layers of the soil during the humid period prevailing just before the advent of rain. Lebedev [1930] has observed a similar phenomenon of the condensation of atmospheric humidities inside the soil depths, and Chaptal [1934] has demonstrated it with limestone pebbles in lysimeters. The desiccation during the dry period releases more solubles [Steenkamp, 1928] but very dry black soil is not easily wetted until subsequent accumulation of condensed water in the more humid periods facilitates wetting on the advent of rains. In addition the daily moisture fluctuations in this more humid period are likely to enable the freshly released bases to enter the clay complex and improve its base-exchange equilibrium. The importance of detailed information about the period and intensities of the several stages in the seasonal recuperation of soils in any locality cannot be over-estimated. Such data alone are the means of devising rational ways for the most efficient practical utilization of the factors operating in nature.

CONCLUSION

Repeated failure to secure, through the action of light, nitrification in treated and untreated soils, kept sterile right up to the end, indicate the absence of any predominant photo-chemical activity. The indispensability of biological action is equally well demonstrated by the presence of nitrification whenever accidental infection occurred. The prevailing high temperatures during the experimental period also prove the possibility of micro-organic activity at least up to 46° C. The continuous existence of nitrifying activity in compost heaps themselves, after a prolonged exposure to high temperature in their initial stages, and even in the hottest surroundings of arid regions, amply supports this view.

Under natural soil conditions, however, nitrification may easily go on at much lower temperatures, being shifted from zone to zone in the soil profile. The intensity of nitrification, also, need not be always at its maximum level. The concentration of microorganic population may not always vary directly with the concentration of the products of their activity in the same zone. The vertical movement of soil moisture should be able to transport the salts from the seat of their production and accumulate them elsewhere. With an adequate understanding of the existing balance of soil processes in a locality it may, after all, be found that the principles underlying them are the same all over the world.

Biological nitrification in watered soils has the appearance of being stimulated by exposure to sunlight but other factors commonly associated with sunlight, *e.g.*, temperature, may sometimes swamp this apparent effect of light, if, indeed it exists.

Continued nitrification gradually reduces its own activity. This point is reached sooner the greater its intensity in the early stages. The steadying influence of compost on nitrification suggests the intervention of organic matter in the process. Under the stimulation by sunlight and its associated temperature rise the lower intensity with ammonium sulphate treatment, coupled with its steadying influence (similar to that of compost), appear to show that the oxidation of ammonium sulphate is brought about by the same agency which oxidises compost and not by a straight-forward chemical reaction.

The modifying influence of moisture supply and organic matter on the effect of sunlight, is well illustrated by the results obtained with dry soils.

There is an indication that the nitrifying activity depletes the soil of the essential material for optimum environment, thus, reducing nitrification with the advance of time. The existence of micro-organic activity at moisture contents very slightly in excess of the hygroscopicity of soils is to be noted. The cent per cent humidity existing in the atmosphere around the soil colloids may, perhaps, be able to maintain a limited extent of film-moisture so essential for micro-organisms. The greater activity of dry soils in the second period with prevailing high humidities in the air seems to justify this assumption. With limited moisture-contents the nitrification in the moisture films may lead to the depletion of the essential ingredients of the soil colloid feeding the organisms in the film, which then becomes unfit to maintain further nitrification.

Temperature must produce a higher degree of fluctuation in nitrification than sunlight, the former influencing the whole soil profile in contrast with the mere surface action of light.

The foregoing conclusions indicate the necessity of estimating the nitrogen nutrition of crops in terms of the resultant effect of all factors involved.

Under the conditions of the experiment, nitrogen was usually lost. There appears to be a sequence of high and low losses. Organic matter showed a steadying influence and sometimes even a gain. There was no consistency in the influence on losses or gains exerted by light and shade. The extent of decrease in subsequent losses shows a relation to the magnitude of their initial increase in soils untreated or treated with ammonium sulphate but with the compost treatment this relation does not hold good. The extent of loss is consistently less in the presence of compost and may even become a gain. The simultaneous occurrence of two independent activities seems to be indicated, one leading to losses and the other resulting in gains, the actual figures indicating a balance between the two. The nature of this balance and the co-existence or otherwise of high nitrification with high gains or high losses of nitrogen, appears to be determined by the existing intensities of the predominant factors mainly responsible for their control. The condition of the argillo-humus complex of the soil seems to be the main determinant, other environmental factors being accessories. The relative extent of aerobic and anærobic conditions in the micro-surroundings of the complex, must obviously vary with that of its coagulated and non-coagulated components, as determined by their composition. The degree of resulting fixation, oxidation or loss of nitrogen will obviously depend upon this essential factor, further modification due to environment (such as temperature and moisture) being additional. The well-known coagulative influence of certain bases on the colloids of the soil complex should obviously play an important part in these phenomena.

Differences in the capacities to lose moisture both in sunlight and in shade bring out the superior mobility of water in treated soils. The increased mobility associated with compost enables a regulation of moisture content favourable for crop-development, moisture being easily reduced when in excess and conserved when deficient. With ammonium sulphate the reverse happens, a condition not congenial for crop-growth. This difference in open textures produced by organic and inorganic substances is noteworthy. It is suggested that a loose mulch maintained on the soil surface may operate just like compost treatment. Moisture is regulated and may be lost, conserved or remain unchanged according to the nature of the environment influencing evapcration.

Dry soils tend to accumulate moisture from the air when humidities are high. An interval of high humidities between the hot, dry season and the advent of rains seems to be an important phase in the process of soil recuperation. The heated but still dry soils with their released nutrients do not soak easily. A slow absorption of water daily fluctuating in degree owing to the weather changes brings about the even incorporation of these released nutrient materials and at the same time enables the soil on the later advent of rains to absorb larger quantities of water quickly. The value cannot be over-estimated of securing accurate information about the extent of these stages in natural soil recuperation in any locality. Means to achieve the maximum development in all these stages should form one of the main items in efficient soil management.

SUMMARY

The nitrogen changes occurring in wet and dry soils, manured and unmanured, were estimated at high temperatures with low and high humidities, in sunlight and in shade. The relative predominance of factors involved was estimated. The results were statistically evaluated.

Results with sterile soils indicated the predominance of biological action but gave no significant evidence of photo-oxidation. The possibility of the accumulation of soil-nitrates by normal micro-organic activity under very drastic conditions is discussed.

Rise in temperature, whether due to direct sunlight or otherwise, and in moisture, intensified nitrification. Nitrogen losses occurred during these experiments with different intensities.

The all-round favourable influence of compost both on the oxidation and conservation of nitrogen under varied surroundings is emphasized. Both compost and ammonium sulphate improved soil texture but the effect on moisture conservation was not the same. The soil processes seem to be affected less by external surroundings than by the properties of the soil-complex which, however, undergoes continuous modification both by the duration of micro-organic activity and by changes in environment. It is suggested that a sound basis for improvements in soil management will be available when accurate information is secured regarding the existing balance in a locality between the several active factors and the limits to their control.

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REFERENCES

Burt, B. C. and Nizam-ud-din Haider (1919). *Imp. Inst. Agric. Res. Pusa, Bull.* **88**, p. 3.

Barthel, Chr. (1930). *Papers and Proc. 2nd Int. Cong. Soil Sci. Leningrad—Moscow. III Commission*, p. 73.

Chaptal, L. (1934). *Les sources secondaires de l'humidite de laterre arable—Proc. 1st Com. Int. Soc. Soil Sci., Versailles.*

Dhar, N. R. and Rao, G. G. (1931). *Soil Sci.* **31**, 379.

Dhar, N. R., Bhattacharya, A. K. and Biswas, N. N. (1933). *Soil Sci.* **36**, 281.

Fraps, G. S. and Sterges. (1935). *Soil Sci.* **39**, 85.

Gardner, R., Alvin, Kezer and Ward, J. C. (1934). *Colorado Agric. Expt. Stn. Tech. Bull. No.* **6**, pp. 20 and 23.

Green, R. A. (1932). *Soil Sci.* **33**, 153.

Hilson, G. R. (1928). *Report on the operation of the Dept. Agric. Madras Presy.*, p. 22.

Kubersingh and Wad, Yeshwant D. (1934). Paper read before Ind. Sci. Cong.

Lebedev, A. F. (1930). *Papers and Proc. 2nd Int. Cong. Soil Sci.—Leningrad—Moscow, VI Commission*, pp. 66 and 67.

Main, T. F. (1908). *Ann. Rept. Expt. work on the Dharwar Agric. Stn., Bombay*, p. 7.

McGeorge, W. T. (1930). *Papers and Proc. 2nd Int. Cong. Soil Sci.—Leningrad—Moscow III Commission*, p. 118.

Sarkaria, Ramsingh, and Fazal-ud-Din (1933). *Ind. J. Agric. Sci.* **3**, 1057.

Sahasrabuddhe, D. L. and Kanitkar, N. V. (1932). *Ind. J. Agric. Sci.* **2**, 455.

Sokolovsky, A. N. (1930). *Papers and Proc. 2nd Int. Cong. Soil Sci.—Leningrad—Moscow—I Commission*, p. 94.

Steenkamp, J. L. (1928). *Soil Sci.* **25**, 163-182.

Tandon, S. P. and Dhar, N. R. (1934). *Soil Sci.* **38**, 183.

Wad, Yeshwant D. and Panse, V. G. (1933). *Ind. J. Agric. Sci.* **3**, 820.

STUDIES IN INDIAN FIBRE PLANTS

NO. 4.—THE ROOT-SYSTEM OF SUNN-HEMP (*CROTALARIA JUNCEA* L.)

BY

R. D. BOSE, B.Sc.,

Special Research Assistant to Imperial Economic Botanist,

M. A. AZIZ, B.Sc. (Agri.),

AND

M. P. BHATNAGAR, B.Sc. (Hons.),

Lately Post-graduate Students, Botanical Section, Pusa

(Received for publication on 4th December 1935)

(With Plates XXVII and XXVIII)

I. Introduction

Sunn-hemp is lately being used in many places as a suitable substitute for Russian hemp (*Cannabis sativa* L.). In view of its growing importance as a fibre crop and its increased popularity as a green manure in the tropics, a detailed study of the crop is desirable. Such a study has, therefore, been taken up at Pusa with the object of breeding strains suitable for the different tracts in India.

A large number of samples of this crop was collected in 1931 from almost all the provinces in India and single plant selections were made from this material. Unlike most of the crops studied in this Section, sunn-hemp is cross-fertilised and this fact has proved a limiting factor in the isolation of pure lines, although some very promising strains have been secured by mass selection.

There is a great deal of variability in the amount of seed-setting, maturity, plant habit and in certain other morphological characters in the cultures under study. As the material was selected from seed samples collected from various parts of the country, differing widely in agricultural as well as in climatic and edaphic conditions, it was natural to expect some variability in the root-system of the cultures as well. A study of the root-system of sunn-hemp varieties was considered to be of fundamental importance and was undertaken in 1933 and 1934 at Pusa. From previous studies with other crops conducted at Pusa it has been established that plants with a deep root-system do not suit climatic conditions usually obtained in Bihar or Bengal, and similarly plants with a shallow root system do not thrive properly in the black cotton soils of Peninsular India.

The heritable tendencies in the different types of root-system of a crop are usually found to be more powerful than the influence of environmental changes and hence a knowledge of the root habit of crops is of great value in problems of plant selections and crop adaptations. The importance of the root habit of crops has been fully realized and increased attention is now being paid by plant breeders to the study of root-systems of different crops. In India itself, Howard and Howard [1917], Venkataraman [1917], Ali Muhammad and Deshpande [1929], Sethi [1929], Kashi Ram and Madhava Rao [1931], Bose and Dixit [1931] and Bose and Joglekar [1933] as well as some others, have made contributions on the subject.

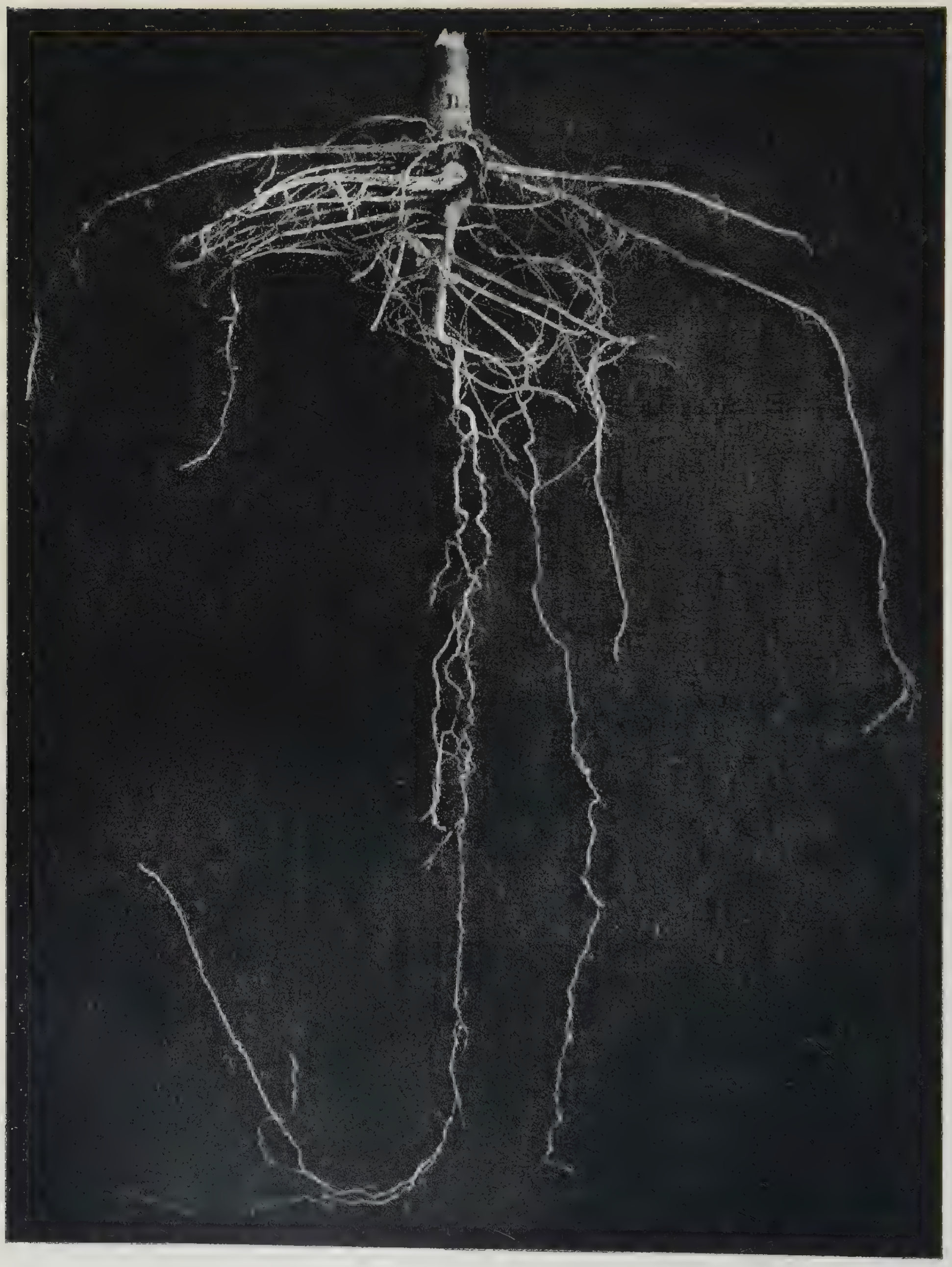
II. Material and method

Sunn-hemp is best adapted to lighter, better-drained lands but is also capable of adapting itself to heavy soils. For the purpose of the present study the crop was grown on a well-drained and slightly clayey loam. The crop showed normal and healthy growth. A number of plants in each culture was examined each year and the averages of all measurements of the extent and distribution of roots were carefully recorded. The method of root-washing and of recording observations were the same as described in a previous publication [Bose and Dixit, 1931].

III. General description

In the year 1933 the roots of all the sunn-hemp cultures were exposed at monthly intervals, beginning one month after the date of sowing. In the case of early observations, however, no clear-cut differences could be found in the development of the main roots till quite a late period in the plant's growth. This periodic root washing showed that the largest number of root tubercles in this crop was found immediately before the flowering stage, and thus to ensure maximum benefit the crop should be ploughed in for green manuring purposes at this stage. Later than this the plants may also become too tough and may not rot so rapidly. It was interesting to note that the cultures with well-developed fibrous roots possessed the largest number of root nodules.

The clearest differentiation between the different types of root-systems is possible when the plants are fully mature, and consequently root washings were made only at this stage in 1934. The observations regarding the depth, extent of lateral spread, working depth, etc., made in 1934 supported and confirmed those made in the previous year.



Mesophytic type of root-system in sunn-hemp.

Sunn-hemp possesses a generalized root-system, a term which indicates that both the tap root and the laterals are very well developed. The copious branching which the roots exhibit, enables the plant to draw its nourishment from a large soil area and the roots usually penetrate the ground deeply and reach out quite widely. The tap root is strongly developed and produces the greater portion of its feeding roots in the upper few inches of the soil. The depth to which the primary roots grow is mainly determined by the drainage conditions and the nature of the soil. In sandy soils, for instance, the tap root invariably grows deeper than in heavy clay loams where it cannot penetrate so far, but under the latter conditions, the secondary roots are generally profuse and more developed. The secondary roots branch off laterally from the primary tap root and in turn produce a large number of tertiary roots. This process of branching continues until the soil is traversed by a complicated network of copiously branched roots making an excellent absorbing system. The lateral roots usually develop below the surface of the soil at a depth varying from half to three inches, but under conditions of excessive soil moisture it is not rare to find them coming up almost to the surface of the soil and these are then liable to considerable damage during inter-cultivation. After growing in a lateral direction for some distance most of the secondary roots usually bend directly downwards, the largest frequently ending in the third or fourth foot of the soil, thus ensuring an adequate supply of soil moisture. It is interesting to note that cultures with the deepest tap roots possess few laterals and form only a small number of fibrous roots and also that very few root nodules are left when the root-systems of fully matured sunn-hemp plants are exposed for examination.

The root-system of the Indian varieties of sunn-hemp may be broadly divided into two main groups, *viz.*, (1) Mesophytic and (2) Xerophytic, each of which may further be sub-divided into two sub-groups. This is in close agreement with the root-systems observed in Indian barleys [Bose and Dixit, 1931] and in green and black grams [Bose and Joglekar, 1933]. A brief description of the types of root-systems usually observed in the case of sunn-hemp is given below :—

I. Mesophytic—A. The tap roots are not very deep, growing generally upto thirty-five to forty inches in depth. There are numerous well-developed secondary roots arising almost at right angles to the tap root. The extent to which these laterals grow horizontally is fairly wide, *i.e.*, from twenty-one to forty inches. Thus they provide the plants with very strong anchorage. Fibrous roots are also very well developed (Plate XXVII).

Mesophytic—B. The tap roots reach a depth of about forty-one to forty-five inches. The secondary roots are found developing up to a greater depth and arise usually obliquely at an angle and finally take a down-ward course, the horizontal spread extending from twenty-eight to thirty-five inches approximately. The fibrous roots are well developed.

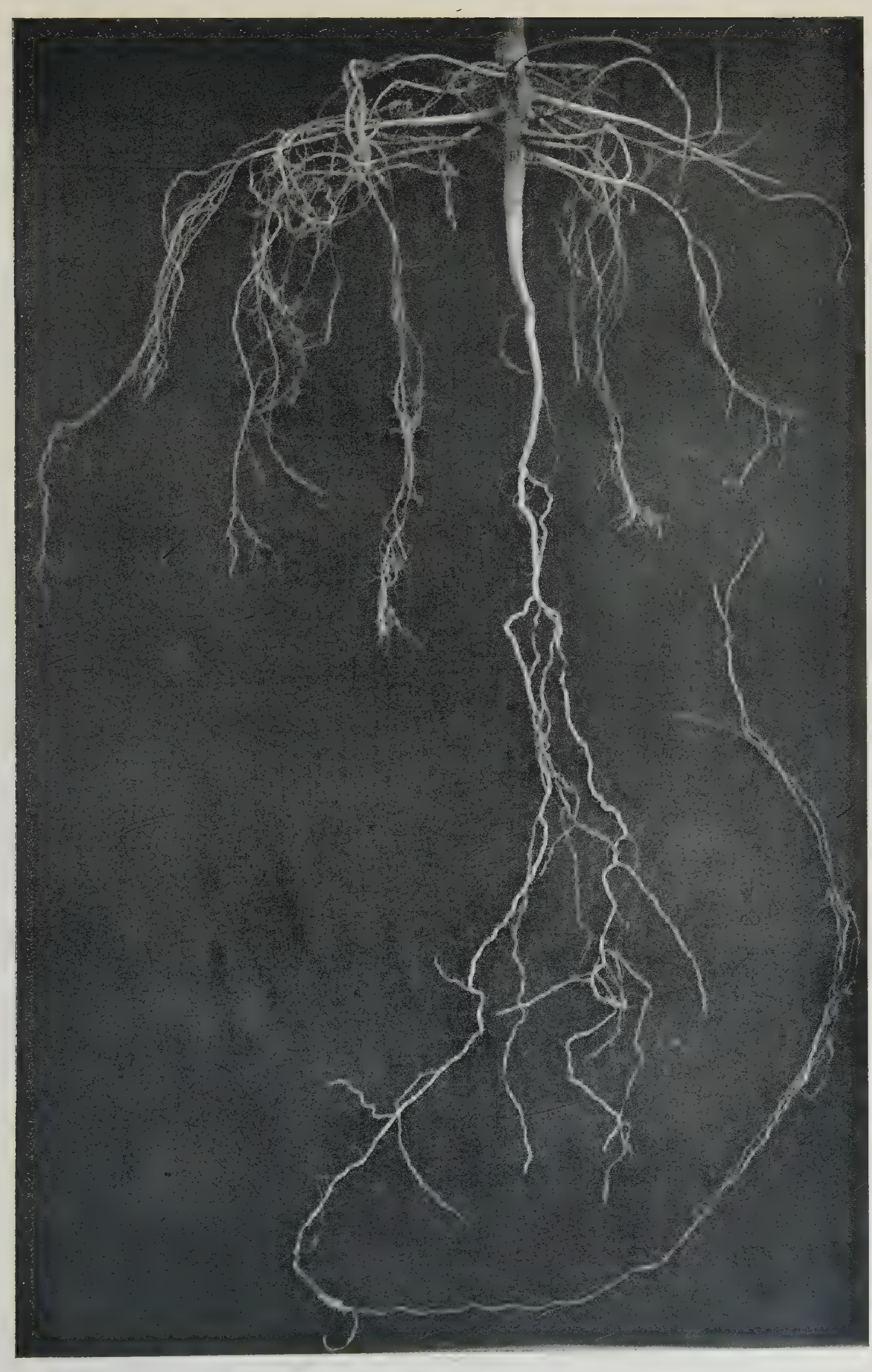
II. Xerophytic—A. The tap root penetrates very deep, generally from forty-six to fifty inches into the soil, and frequently gives out delicate branches at a depth of about twenty to twenty-five inches. A few well-developed but sparsely branched secondary roots arise within a depth of six or seven inches of the soil and the horizontal spread is not very wide and covers a distance of about fifteen to twenty-eight inches only. The fibrous roots are poorly developed and are mostly at the lower levels of the soil (Plate XXVIII).

Xerophytic—B. The tap root goes down very deeply, usually more than fifty inches in depth. The secondary roots which are rather sparsely developed, arise within a few inches from the surface of the soil at a distinct angle to the tap root and almost immediately pursue a downward course. The fibrous roots are usually poorly developed and are again mostly at the lower depths of the soil.

The relevant data concerning this investigation are presented in Table I. It must be remembered however, that the measurements given in this table, as well as in the other tables, have been based on the mean values of the accumulated data for the two years under consideration. They are, therefore, not absolute but only comparative and may be expected to vary under different soil and climatic conditions. The depth of the tap root and the lateral spread of secondary roots in culture 8-2 (Xerophytic—A) in two fields in 1934 will furnish a good example of the nature of this change :—

Culture No.	Field	Nature of soil	Maximum depth of tap root in inches	Lateral spread of secondary roots in inches	No. of secondary roots
8-2 . . .	Barah South border.	Clayey loam.	47	24	6
8-2 . . .	Farm Plot 1 .	Sandy loam .	53	18	9

It is obvious that the depth of tap roots and the number of secondary roots are greater in sandy loam than in clayey soil, but the lateral spread of the secondary roots is definitely less in the former case.



Xerophytic type of root-system in sunn-hemp.

TABLE I

Root-systems and some other characters in sunn-hemp cultures

Nature of root-system	Culture No.	Locality of origin		Maximum depth of tap root	Lateral spread of secondary roots	*Working depth	Development of fibrous roots	Average height of plants	Plant habit
		Province	Place						
				(in.)	(in.)	(in.)		(in.)	
Mesophytic—A	5-1	Assam	Gauhati	38	24	4	Fair	98	Erect
	5-2	Do.	Jorhat	39	30	4	Fair	89	Erect
	1-1	Bengal	Faridpur	40	28	5	Fair	110	Erect
	1-2	Do.	Barisal	40	24	5	Good	104	Erect
	2-3	Do.	Feni	36	28	5	Good	100	Erect
	27-2	Bihar	Pusa	40	27	5	Very good	98	Spreading
	27-1	Do.	Darbhanga	36	30	6	Very good	98	Spreading
	32-1	Do.	Muzaffarpur	40	25	6	Very good	99	Spreading
	32-2	Do.	Sepaya	36	35	6	Good	114	Spreading
	11-1	Madras	Giddalore	38	32	6	Good	106	Erect
Mesophytic—B	10-2	Madras	Giddalore	45	24	4	Good	98	Erect
Xerophytic—A	11-2	Sind	Sakrand	46	26	6	Fair	105	Erect
	11-(*a*)	Bombay	Jalgaon	48	18	6	Poor	99	Erect
	3-2	Central Provinces.	Nagpur	50	26	5	Poor	98	Erect
	30-2	Do.	Balaghat	48	22	5	Fair	118	Erect
	8-2	Central India	Indore	48	24	4	Fair	107	Erect
	16-2	United Provinces.	Aligarh	46	25	4	Fair	102	Erect
	20-2	Do.	Sandilla	48	22	4	Poor	110	Erect
	6-2	Do.	Cawnpore	51	25	4	Poor	106	Erect
	17-1	Madras	Palghat	49	21	4	Poor	110	Erect
Xerophytic—B	8-12	Central India	Mhow	52	25	6	Poor	114	Erect
	7-2	Do.	Indore	68	14	6	Fair	114	Erect
	1-(*b*)	Punjab	Multan	64	19	6	Fair	126	Erect
	11-(*b*)	Bombay	Jalgaon	56	20	6	Poor	100	Erect

---

* Working depth may be defined as the depth from the soil surface at which the maximum number of lateral roots are given off. In the case of sunn-hemp the variability in the working depth of the root-system is not as great as has been found in *mung* and *urid* [Bose and Joglekar, 1933].

The maximum depth of the tap root is considered as one of the chief criteria for the differentiation of the types of root system. The distribution of the different cultures according to this character is shown in Table II given below :—

Table II

Relation of the type of root-system to the maximum depth of the tap root

Range of maximum depth of tap roots in inches	Cultures with root-system			
	Mesophytic—A	Mesophytic—B	Xerophytic—A	Xerophytic—B
34 to 36 . . .	2-3 ; 27-1 ; 32-2.			
37 to 39 . . .	5-1 ; 5-2 ; 11-1			
40 to 42 . . .	1-1 ; 1-2 ; 27-2 ; 32-1.			
43 to 45 . . .		10-2		
46 to 48 . . .			8-2, 11-2, 11 (*a*), 16-2, 20-2, 30-2.	
49 to 51 . . .			3-2, 6-2, 17-1	
52 to 54 . . .				8-12
55 to 56 . . .				11-(*b*)
57 to 59 . . .				
60 to 62 . . .				
63 to 65 . . .				1-(*b*)
66 to 68 . . .				7-2

It is evident from the above that there is a definite range in the maximum depths of tap roots for the different types of root-systems.

The relation of the type of root-system to the lateral spread of the secondary roots is similarly brought out in the following table :—

TABLE III

Relation of the type of root-system to the lateral spread of secondary roots

Lateral spread of secondary roots in inches	Cultures with root-system			
	Mesophytic—A	Mesophytic—B	Xerophytic—A	Xerophytic—B
12·6 to 15·0				7-2
15·1 to 17·5				
17·6 to 20·0			11-(*a*)	1-(*b*) ; 11-(*b*)
20·1 to 22·5			17-1 ; 20-2 ; 30-2.	
22·6 to 25·0	1-2 ; 5-1 ; 32-1.	10-2	6-2 ; 8-2 ; 16-2.	8-12
25·1 to 27·5	27-2		3-2 ; 11-2	
27·6 to 30·0	1-1 ; 2-3 ; 5-2 ; 27-1.			
30·1 to 32·5	11-1			
32·6 to 35·0	32-2			

In this case it is seen that the lateral spread of secondary roots in the mesophytic type of root-system is greater than that in the xerophytic type. Only four cultures with a spreading plant habit, *viz.*, cultures 27-1, 27-2, 32-1 and 32-2 were examined and they invariably had a larger amount of foliage development coupled with greater spread of lateral roots and also a better development of fibrous roots than the other cultures, all of which possessed erect plant habit. This of course is in conformity with the physiological fact that the plants with greater amount of foliage development require more efficient and vigorous root-systems capable of extending over a wide range of soil surface. The cultures with spreading plant habit, therefore, possess greater potentialities as green manuring crops for higher nitrogen fixation and humus formation, because of their well-developed root systems and nodule development as well as due to their heavy foliage growth. It is obvious also that the proper spacing for this crop should vary directly with the type of root-system and the extent of the lateral spread of the secondary roots.

The development of the fibrous roots and consequently of root nodules, is usually good in the cultures with mesophytic roots and mostly poor or only fair in the case of cultures with the xerophytic type of root-system. This character is of great economic importance because the greater the number of fibrous roots in a plant, the larger is the formation of root nodules containing nitrogen-fixing bacteria. Sunn-hemp strains possessing this character, therefore, should be very useful for green manuring purposes.

IV. Relation of the type of root-system to locality

The distribution of the different types of root-systems found in any crop is obviously centred round two important points, *viz.*, (1) soil æration and (2) the capacity of the soil to retain moisture. The presence of sufficient moisture and available food materials in the upper layers of the soil, as well as the anaerobic condition of the lower levels in Assam, Bengal and Bihar, or as a matter of fact in the greater part of the Gangetic alluvium, makes this tract an ideal substratum for surface rooting types. It is no wonder that the cultures with the mesophytic type of root-system, in the present studies, have originated from seed collected from these localities. Cultures 10-2 and 11-1 are exceptions, as the original seed of these strains was collected from Giddalore in the Madras Presidency. On the other hand, the drier soils of Western parts of the United Provinces of Agra and Oudh, and the greater portion of the Punjab, Sind and of Peninsular India, including Central India, the Central Provinces and the Presidencies of Madras and Bombay, with their deeper-seated supplies of moisture and better æration at the deeper levels of the soil, are adequately fitted for the growth and development of sunn-hemps possessing the xerophytic type of root-system. It is indeed from these tracts that cultures with xerophytic roots have been drawn. The results presented in these studies, therefore, again confirm those obtained in other crops like barley, *mung* and *urid* reported before from this Section [*loc. cit.*]

Though root habit is rather responsive within certain limits to environmental conditions, its growth is primarily governed by heritable factors. In order to derive maximum benefits from improved crops, it is of fundamental importance for the plant breeder to appreciate the need for selecting plants with the proper type of root-system, suitable for the locality for which he is evolving his type. It will not do, for instance, to select for the black cotton soils of Central India a sunn-hemp variety possessing mesophytic type of roots.

V. RELATION OF THE TYPE OF ROOT-SYSTEM TO PLANT STATURE

The root-system of a plant is often said to be the image of the shoot system and frequently it is found that the taller the plant the greater is the depth of its roots. The maintenance of the proper balance between the root and the shoot of a plant is indeed of very great imporatnce ; if either is too limited or too great in extent, the other will not thrive normally. In a healthy and well developed plant the root-system must be sufficiently wide-spread to absorb enough water and nutrients for the stem and leaves, which in their turn must manufacture sufficient food for the maintenance of the root-system and for the plant as a whole.

Moderately high positive correlation ($r=0\cdot4579\pm0\cdot1088$) is found in the present studies between the average height of sunn-hemp plants and the maximum depth of their tap roots. This must not, however, be taken to indicate that all cultures which are tall must necessarily possess the deepest going tap roots or *vice versa*, for there are a number of sunn-hemp cultures at Pusa which are tall but which definitely have a mesophytic type of root-system. These cultures have a large number of secondary roots and abundant fibrous roots. In other words, the association between the type of the root-system and stature in sunn-hemp may be said to be close and the amount of root development, including the depth of the main tap root, the lateral spread of secondary roots and the nature of the tertiary roots, may be said to be proportional to the development of the above-ground parts and consequently to the stature of the plant within certain limits.

VI. SUMMARY AND CONCLUSIONS

The study of the root-system of an economic crop is as important as that of its above-ground parts and the best results can be achieved from improved strains of crops only if their root-systems are efficiently adapted to the soil and climatic conditions under which they have to be grown.

At Pusa a number of sunn-hemp cultures have been evolved from material collected from different parts of India. The root-systems of twenty four cultures, representative of different tracts, have been studied for two years consecutively.

Two definite types of root-systems, *viz.*, mesophytic and xerophytic, have been recognised and differentiation between these two types has been made mostly according to the depth of the tap roots, the lateral spread of the secondary roots, and the nature and development of the fibrous roots. Further sub-divisions between mesophytic A and B and xerophytic A and B have also been made on the basis of the average depth of the tap roots.

In the mesophytic type of root-system the tap roots had lesser depths and the secondary roots had a greater spread than in the xerophytic type. Cultures which were collected from the alluviums of Assam, Bengal and Bihar and a very few others, invariably had a mesophytic type of root system, whereas cultures which were selected from seed collected from the drier localities of the United Provinces of Agra and Oudh, parts of the Punjab, Sind and Peninsular India, exhibited the xerophytic type of root-system. Moderately high positive correlation has been observed between the type of root-system and the stature of plants.

REFERENCES

Ali Mohammed and Deshpande, R. B. (1929). *Agric. J. Ind.* **24**, 251-258.

Bose, R. D. and Dixit, P. D. (1931). *Ind. J. Agric. Sci.* **1**, 90-108.

Bose, R. D., and Joglekar, R. G. (1933). *Ind. J. Agric. Sci.* **3**, 1045-1056.

Howard, A. and Howard, G. L. C. (1917). *Agric. J. Ind.*, **12**, 17 (*Indian Science Congress Number*).

Kashi Ram and Madhava Rao (1931). *Ind. J. Agric. Sci.* **1**, 715.

Sethi, R. L. (1929). *Mem. Dept. Agric. Ind., Bot. Ser.* **18**, No. 2.

Venkatraman, T. S. (1922). *Agric. J. Ind.* **17**, 381.

EARLINESS IN THE UNITED PROVINCES RICES

BY

R. L. SETHI, M.Sc., B.Sc. (Edin.), I.A.S.,
Economic Botanist (Sugarcane and Paddy) to Government, United Provinces,

B. L. SETHI, M.Sc., Ph.D. (Wales),
Assistant Paddy Specialist,

AND

T. R. MEHTA, B.Sc.,
Research Assistant, Rice Research Station, Nagina

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(With two text figures)

CONTENTS

		PAGE
I.	INTRODUCTION	361
II.	NECESSITY OF EARLY RIPENING TYPES IN U. P.	362
III.	EARLINESS IN U. P. RICES	362
IV.	CRITERION OF EARLINESS	363
V.	FLOWERING IN RELATION TO SEASONAL FACTORS AND TO THE AGE OF SEEDLINGS AT THE TIME OF TRANSPLANTING	364
VI.	FLOWERING IN RELATION TO RIPENING	370
VII.	SUMMARY AND CONCLUSIONS	375
	REFERENCES	376

I. INTRODUCTION

This note deals with some aspects of earliness in the rice crop studied during the last nine years, first at the Botanical Section, Cawnpore, and later at the Rice Research Station, Nagina. The facts described below have been collected from observations on pure lines, and are described here as a preliminary to the proper understanding of the data accumulated since 1929 on the inheritance of earliness to be described in a subsequent paper. The studies with the pure lines and the hybrid materials are the outcome of the fact that earliness is one of the most important characteristics which decide the popularity or otherwise of a variety in a locality ; hence in our programme of rice improvement in the United Provinces, adequate attention has been paid to this aspect of the crop.

II. NECESSITY OF EARLY-RIPENING TYPES IN THE UNITED PROVINCES

The demand for early-ripening types is great in several districts of the United Provinces. Besides enabling the cultivator to clear his field in time for the sowing of gram or wheat which generally follows paddy in rotation, early varieties make less demand on water on account of their shorter growing period. Since many parts of the United Provinces, where paddy forms an important crop, are not so well supplied with rain as other rice growing provinces like Bengal, Madras or Burma, and since the monsoon stops in September or the beginning of October, it is very important that the paddy varieties should be such as to ripen just after the withdrawal of the monsoon. Even in areas where facilities of irrigation by canal are available (and these have increased considerably in recent years due to the opening of the Sarda Canal) the earlier ripening varieties are generally preferred by the cultivators.

III. EARLINESS IN UNITED PROVINCES RICES

The transplanted rices of the United Provinces can be broadly classified into early and late types. The early types flower from the end of August to the third week of September if sown in the first week of June and transplanted about four or five weeks after. They are ready for harvest in October. The late types flower from about the second week of October to the last week of the same month mostly between the 10th to 20th October, and are ready for harvest in the later half of November or in early December. This division of the United Provinces rices into two main groups is definite, very few types flowering in the intermediate period, *viz.*, the end of September or the beginning of October. The flowering of pure lines grown every year at the Rice Research Station, Nagina, which represent the majority of the rices of the United Provinces, gives a correct picture of the facts. Their flowering is shown in Figure 1. The earliest types start flowering in the end of August, *i.e.*, about eighty to ninety days after sowing, the latest in the early group taking as many as 112—115 days to flower.

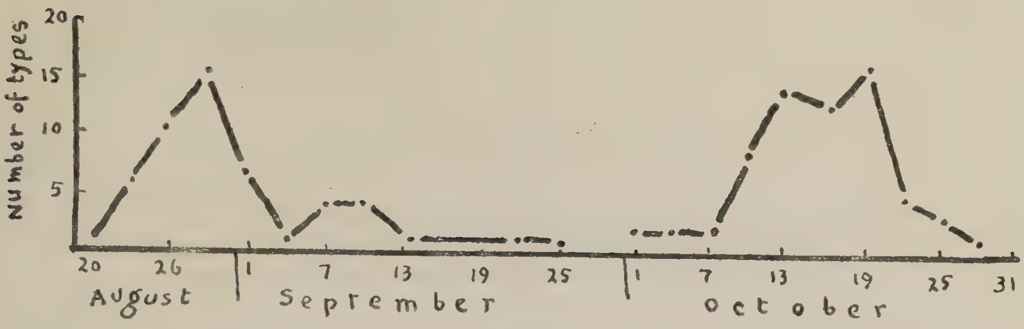

Fig. 1. Showing distribution of U. P. rices into two main groups, one early and the other late.

Among the late types the earliest to flower takes 120 days from sowing, the latest taking as many as 145 days. These figures vary slightly from year to year. The difference of the means of the two groups can be conveniently taken to be over a month. In Fig. 1 the modes are separated by about seven weeks.

Besides the transplanted rices there are a few broadcast rices. Of these, the most popular are those commonly called *Sathi dhan* (paddy). *Sathis*, as the name implies, take about sixty days to ripen after sowing. They are the earliest rices of the United Provinces, the other broadcast rices being a few to several weeks later than the *Sathis*.

IV. CRITERION OF EARLINESS

Before studies upon earliness are made it has to be decided how best to judge earliness ; in other words, what should be the criterion of earliness ? The available literature on cereal crops in general shows that many workers have recognised the date of earing as the most suitable criterion for judging earliness, although other criteria have also been frequently used. Thus Farrer [1898] selected as his index the change of colour of the peduncle immediately below the spike. Biffen [1905], working on wheat, judged the fully ripe condition by the yellowing of straw and glumes and the hardening of the grain. Thompson [1918] used the term " fully ripe " when the central kernels of the wheat spike reached the dough stage. Caporn [1918] in his studies on oats considered a plant fully ripe when the last trace of greenness had disappeared from the tips of the palae. On the other hand Freeman [1919], Bryan and Pressley [1921], Florell [1924], and Allen [1924], all working on wheat, have used as the index of earliness the date of appearance of the first head on each plant.

Hoshino [1915] and Jones [1928], working on rice, selected as their index of earliness the appearance of the first spikelet above the sheath of the inflorescence. The latter says " This index of earliness was found to be more satisfactory than a record of the date when the plant is fully headed or the kernels are all ripe ".

Ayyangar [1921] used the date on which the first main head emerges out of the sheath and shows the white downy ring at the bottom of the panicle for flowering in rice, although he does not mention that he used the flowering duration as an index of earliness.

We have also used the date of emergence of the tip of the panicle above the sheath as the index of earliness. The following reasons are suggested for this :—

1. The exact date of flowering can be judged more easily and with fairer accuracy than probably any other factor like, say, the ripening of the complete ear or the yellowing of the peduncle.
2. The ripening can be abnormally affected by adverse climatic or soil conditions, but flowering is not influenced to the same extent.

Whatever criterion is used for judging earliness it should fulfil certain important conditions. It should, for example, be accurate, and reliable. As for accuracy probably no other character can be judged with greater precision and ease as the date of flowering. With regard to reliability the date of flowering is not perhaps so consistent. It may show variation from year to year, besides being affected by spacing, manurial application, age of seedlings at transplanting, etc., but even then it is probably more consistent than ripening.

In view of the importance of earliness and the necessity for caution in drawing conclusions from a study of flowering (liable as it is to variations due to the above-mentioned factors), it is proposed to examine the effects of some of the factors on flowering. We shall first consider the relation of flowering to seasonal factors, and also examine the effect on flowering of the age of seedlings at the time of transplanting.

V. FLOWERING IN RELATION TO SEASONAL FACTORS AND TO THE AGE OF SEEDLINGS AT THE TIME OF TRANSPLANTING

The flowering dates were noted in 135 pure lines, isolated in the years from 1926 to 1929 [Sethi and Saxena, 1930], when the observations were discontinued except in the case of a few types which were used as parents for certain crosses. Observations are now available extending over seven years on eight of the pure lines, four early and four late, and it is proposed to examine them closely in order to study the variation in their flowering durations.*

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* The following terms will be used in connection with the work here described.

Flowering duration is the total number of days between sowing and flowering.

Time of flowering is the particular day on which a plant is observed to begin flowering.

Flowering period is the number of days between the beginning and end of flowering in a culture.

Ripening duration is the total number of days between sowing and ripening.

Ripening period is the interval between flowering and ripening.

The first three terms are borrowed from the paper on "Inheritance of flowering duration in rice" by Ramiah [1933].

The flowering durations of the eight pure lines referred to above are given in Table I.

TABLE I

Flowering durations of eight pure lines in 1926-33

Year	Age of seedlings at transplanting	Early types				Late types			
		T. 1	T. 3	T. 7	T. 12	T. 5	T. 26	T.100	T.110
	Days								
1926 . .	43	101	103	97	99	136	129	133	136
1927 . .	33	90	95	89	88	135	130	132	134
1928 . .	36	92	90	90	94	132	125	126	131
1929 . .	30	81	93	77	84	132	120	122	130
1931 . .	36	89	102	89	95	135	126	128	131
1932 . .	32	85	96	85	86	133	123	129	133
1933 . .	32	86	99	85	92	138	128	129	135

It can be seen that marked variation occurs from year to year.

A close examination of the table reveals an interesting relationship between the flowering duration and the age of the seedlings at the time of transplanting. The flowering duration runs more or less parallel with the age of the seedlings, being lengthened with an increase in age. This parallelism will become more apparent when the flowering durations are represented as the averages of the four early and four late types as in Table II.

TABLE II

Variation in flowering duration with the age of seedlings at transplanting

Year	Age of seedlings at transplanting	Average flowering durations	
		Early types	Late types
	Days		
1926	43	100·00	135·50
1927	33	90·50	132·70
1928	36	91·50	128·50
1929	30	83·75	126·00
1931	36	93·75	130·00
1932	32	88·00	129·50
1933	32	90·50	132·50

If, as the figures in the above table suggest, there does exist a tendency for the flowering duration to lengthen with the age of seedlings, the bearing of this fact upon all studies of earliness will be as stated below. In breeding studies it is usual to accumulate data over a number of years in order to study the genetic variability of cultures for tracing relationship between different cultures in the same year or of different generations in different years. It is apparent, therefore, that the studies will not be quite accurate if the relationship between flowering duration and the age of seedlings is disregarded. In view of this fact it is proposed to treat the figures in Table II statistically in order to judge the reliability as well as the intensity of the relation suggested by the figures.

The relation has been tested by estimating the coefficient of correlation between the two sets of variables. The method used is the usual product moment formula :

$$r = \frac{S\,(xy)}{\sqrt{S(x^2).\;S\,(y^2)}}$$

where x and y are the differences of the variables from their respective means. The values of r for the early and late types are, respectively, $+0{\cdot}8153$ and $+0{\cdot}5320$, the two standard deviations being $\pm 0{\cdot}1368$ and $\pm 0{\cdot}2931$. For a small sample of the size we are dealing with (*viz.*, seven pairs of observations) the value of r and its relation to its standard error cannot be depended upon to measure the significance of the correlation observed. This fact has been emphasized by Fisher [1932] who has described a special method which he terms 'transformed correlation'. According to this method the value of r is transformed into a value called z, and to facilitate the transformation Fisher has prepared a table [1932, Table VB]. Thus—

when $r=0\cdot8144$, $z=1\cdot14$
when $r=0\cdot8178$, $z=1\cdot15$

By interpolation we find that for $r=0\cdot8153$, $z=1\cdot1427$. The standard error of z calculated according to the formula—

$$\sigma_z = \frac{1}{\sqrt{n-3}}$$

is $0\cdot5$. The ratio of $z : \sigma_z$ in the present case is $2\cdot2854$, which is interpreted as a normal deviate. Now, from tables of normal deviates we find that the deviation in the normal distribution in terms of the standard error should be as follows :—

For $P=0\cdot01$ deviation should be $2\cdot575829$
$P=0\cdot02$, ,, ,, $2\cdot326348$
$P=0\cdot03$, ,, ,, $2\cdot170090$

Our value of $z : \sigma_z$ is $2\cdot2854$ which is between $0\cdot02$ and $0\cdot03$ points of P.

Thus the value of r for the early types can be regarded as significant. In other words, the coefficient of correlation, $+0\cdot8153$, may be regarded as sufficiently high to indicate a relationship between the age of seedlings and the date of flowering in the early types. We do not know whether it is the factor of the age of seedling or the climatic conditions obtaining at the time of transplanting which has given to the figures a correlational semblance. That there is something more than accident in this relationship is what we were led to suspect in the course of the last few years' breeding work, even before the figures were statistically analysed. The observations on late cultures also led to the conclusions confirmed above, *viz.*, that delayed transplanting does not delay flowering to the same extent as it does in the case of early cultures.

An experiment in randomized blocks was laid down in 1934 to test the above finding regarding the age of seedlings and flowering duration. The average flowering date of each of the plots was noted during the course of field observations.

The ages of the seedlings used at transplanting were fifteen, twenty-five, thirty-five and forty-five days. Transplanting of the different treatments was done on the same day. The results obtained were as follows :

Age of seedlings	Average flowering duration
15 days	79 days
25 days	87 days
35 days	98 days
45 days	109 days

Thus the flowering duration has been remarkably affected by the age of the seedlings.

The above fact also finds support from the flowering data collected from some of the pure lines in 1933. One of these types was transplanted on different dates from seed sown on the same date. The frequency distributions are given in Table III.

TABTE III

Frequency distributions of flowering duration of T. 1 transplanted on different dates in 1933

Flowering duration in days

Date of sowing	Date of trans-planting	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	Mean	Standard devia-tion	Coefficient of varia-tion
3rd June .	3rd July .	1	...	7	2	19	7	5	7	3	5	...	2	...	...	...	...	...	...	...	86·02	2·36	2·74
Do. .	Do. .	1	1	3	1	24	17	17	4	7	9	...	1	...	...	...	...	...	...	...	86·52	2·01	2·32
Do. .	4th July .	...	...	...	...	1	5	5	4	12	11	25	11	4	5	2	...	...	...	...	90·34	2·16	2·39
Do. .	6th July .	...	...	...	2	...	10	9	26	7	27	18	10	3	4	2	...	...	...	...	89·45	2·21	2·47
Do. .	Do. .	...	...	1	...	...	15	11	29	13	12	7	...	7	...	...	...	...	...	...	88·49	1·96	2·21
Do. .	Do. .	...	...	...	...	...	3	1	15	21	21	13	6	3	2	1	...	...	...	...	89·78	1·70	1·89

It will be seen that the mean flowering duration varies slightly with the date of transplanting.

In view of the relation between flowering and the age of seedlings at transplanting it becomes quite clear how important it is in experiments, where a comparison has to be made of earliness in various cultures, that transplanting be confined within as narrow a range of time as possible. Usually at a research station the number of such cultures is large and the transplanting has to be carried out over a number of days, especially when heavy monsoon showers interfere with speedy work. This is likely to affect the flowering. Hence an attempt should be made to transplant cultures, whose flowering durations have to be accurately compared on the same date, and towards this end all the resources of the station should be employed.

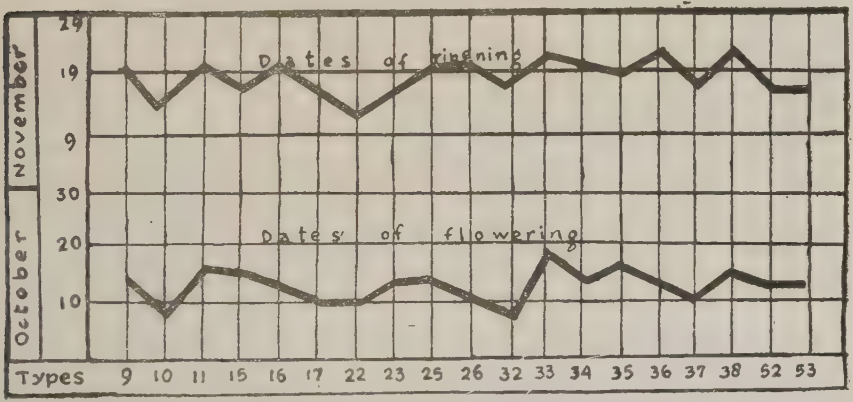
Very much delayed transplanting was observed to have a curious effect on the flowering of some of the early types in 1934. Some of the seedlings of these early types were transplanted very late (about two or three weeks after the normal time) in order to fill in gaps caused by seedling mortality. These seedlings were obtained from the original nursery. The original transplanted seedlings pursued a normal course of development, each forming several tillers before commencing flowering. The later transplanted seedlings, however, consisting in most cases of a single tiller from the nursery started bearing thin poor ears within a few days of transplanting. This hastening of flowering was probably due to the plants having enjoyed a long uninterrupted growth in the nursery where they had already attained a high stage of development and were ready for flowering when uprooted, so that as soon as they were transplanted they formed ears. The earlier transplanted crop on the other hand, having received a check due to transplantation earlier in life proceeded with fresh vegetative activity before entering the flowering phase. Since the second transplanting was delayed abnormally the hastening of flowering cannot be said to be an effect of " age of seedlings " but is perhaps an expression of the ' periodicity ' of the crop. In these plants the real flowering took place when they renewed their vegetative activity after the first tiller had matured and the subsequent tillers flowered appreciably later than the rest of the crop from the first transplanting.

VI. FLOWERING IN RELATION TO RIPENING

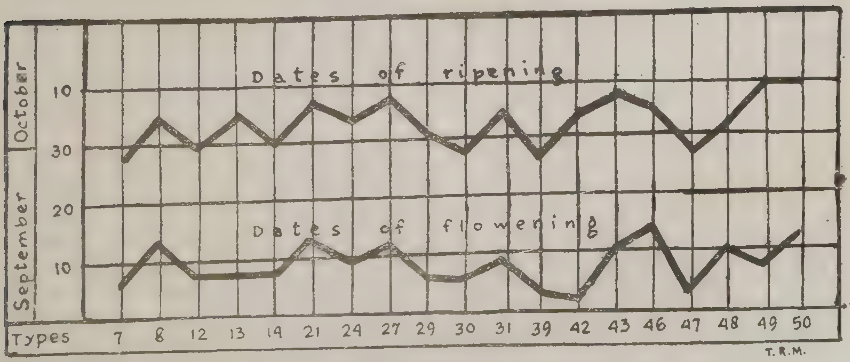
In the study of flowering as an index of earliness we should not overlook the relation of flowering to ripening, because it is the latter phase which is most important to the cultivator. We shall therefore see whether the time which elapses between the flowering and ripening (*i.e.*, the ripening period) is constant for all the varieties, and also, whether in a particular variety it varies from year to year. This will show us how far earliness in flowering is a true index of earliness in ripening, and how far the former character can be relied upon in judging the latter.

It has been found that for a particular variety the ripening period is more or less constant for a particular locality. Slight variations may, however, be caused from year to year by climatic factors. Further, early varieties have, on the whole, shorter ripening periods than late ones. In other words, the former take less time to ripen after flowering is over than the latter. This fact is brought out clearly in Fig. 2, where the thick lines represent the dates of flowering and of ripening in some of the early and late pure lines. Two facts are clear from the graphs :—

1. The ripening period does not vary much within the group of early or late types, the ripening tending to vary with flowering. This is evident from the tendency of the flowering and ripening lines to remain parallel.
2. The ripening period of late types is distinctly longer than that of the early types. This is seen from the wider space separating the two lines in the former.



LATE TYPES



EARLY TYPES

Fig. 2. Showing the ripening period in early and late type in 1928.

The latter fact was mentioned in an earlier publication [Sethi and Saxena, 1930], but the data had not been studied systematically. The data have since been closely examined and now enable us to arrive at definite conclusions. Three years' data (1926-28) on about 120 pure lines have been analysed. These pure lines comprise both early as well as late types. For each group the average flowering and ripening durations† were calculated, and the averages examined statistically. The data are summarised in Table IV.

TABLE IV

Flowering and ripening durations and ripening periods in early and late types in 1926-28

Year	Nature of types	No. of types	Mean flowering duration (A)	Mean ripening duration (B)	Mean ripening period (B—A)	Variance of ripening period	Mean difference between ripening periods of early and late types	$t = \frac{\text{mean difference}}{^{*}\text{S.E. of mean difference}}$
1	2	3	4	5	6	7	8	9
1926 .	Early	53	102·62	130·43	27·81	16·46	12·09	16·20
	Late .	63	133·02	172·92	39·90	15·51		
1927 .	Early	54	92·93	120·43	27·50	12·03	7·99	12·54
	Late .	67	132·76	168·25	35·49	12·28		
1928 .	Early	53	94·58	121·50	26·92	15·30	8·13	11·32
	Late .	66	128·24	163·29	35·05	15·02		

* The values of '*t*' for 0·01 point of *P* for populations of 30 and infinity are, respectively, 2·750 and 2·5782. The observed values of '*t*' are markedly higher than these.

The differences between the ripening periods of the early and the late types in 1926, 1927 and 1928 are 12·09, 7·99 and 8·13 days, respectively. These figures represent averages of over fifty types (Table IV). The differences have been statistically examined and are found to be significant. The method used is Fisher's '*t*'-test [Fisher, 1932] devised for comparison of mean values based on small samples. The formula is—

$$t = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}}$$

---

† It has already been stated that ripening cannot be noted with the same accuracy or reliability as flowering. The ripening durations mentioned here are therefore rough approximations, arrived at after close examination of the panicles for maturity which necessitated greater care and more attention than the noting of flowering date usually does.

where $\tilde{x}_1$ and $\tilde{x}_2$ are the two means, S_1^2 and S_2^2 the estimates of two variances and N_1 and N_2 are the sizes of the samples.

The calculation of '*t*' for 1926 data is given below :—

$$t = \frac{12\cdot09}{\sqrt{\frac{16\cdot46}{53}+\frac{15\cdot51}{63}}}$$

$$= \frac{12\cdot09}{0\cdot7462} = 16\cdot20$$

This value and the values of '*t*' for 1927 and 1928 are higher than the values required for 0·01 probability. We may therefore state that the relation of flowering to ripening is not identical in the early and late types, because the ripening periods in the two cases are different. This fact affects the study of earliness thus. If two types, one early and one late, have a difference of, say, forty days in flowering, they will be ready for harvest with a difference, not of forty days, but longer. The latter, when compared with the former only on the basis of the flowering duration will, therefore, appear more precocious than it really is. This remark may equally well apply to early and late segregates of the crosses to be described in a subsequent paper. Thus flowering, possessing as it does different indicative values for early as compared to the late types, loses some of its merit of being the best criterion of earliness.

The examination of the statistics of the flowering and ripening of the pure lines has further enabled us to test whether within the same group of types (*i.e.*, early or late group) the types which flower earlier have shorter ripening periods. It is evident that such a relation will best be revealed by computing the coefficient of correlation between the flowering durations and the ripening periods. This was done separately for the years 1926, 1927 and 1928 for early and late types considered separately as well as together. The nine values of the coefficients of correlation are given in Table V, with their standard errors.

TABLE V

Values of coefficient of correlation (r) *between flowering duration and ripening period in early and late types*

Year	Description of group	No. of types	r	$\sigma\ r$
1926	Early types	53	+0·283	0·1276
	Late types	63	+0·261	0·1184
	Early and late types	116	+0·496	0·0700
1927	Early types	54	—0·057	0·1369
	Late types	67	+0·103	0·1218
	Early and late types	121	+0·795	0·0335
1928	Early types	53	+0·160	0·1351
	Late types	66	+0·228	0·1176
	Early and late types	119	+0·730	0·0428

The values of *r* (Table V) show that the correlations are low and, in most cases, insignificant where the early or the late group is considered separately. That is, within a group, the ripening period is not necessarily greater in a type which has a larger flowering duration than in one with a shorter duration. On the other hand, when both the groups are considered together the correlations are always positive, close and significant. The facts can be interpreted thus. The low correlation within each group indicates that within a group the types may be considered genetically alike so far as the relation between their flowering durations and ripening periods is concerned. The high correlations when the two groups are considered together indicate that these groups are genetically different, the shorter duration group (*i.e.*, the early types) possessing a shorter ripening period than the other group.

It was surmised in a previous publication [Sethi and Saxena, 1930] that the difference in the ripening periods of early and late types may be due to the gradual fall in temperature from August onwards. The temperature by the end of September or the beginning of October, when the early types mature, is about 98° F., while about the beginning or middle of November, the time of maturity of late types, it ranges between 80° and 84° F. While there is a possibility of such an influence operating, it is felt that without controlled experiments in green houses this view is open to criticism. It may be that the fall in temperature is not the prime cause, but that the growth factors which determine flowering duration also determine the ripening period. Thus we may reasonably expect that if one phase of the life of the late types is longer (*viz.*, the flowering duration) the next phase (*viz.*, the ripening period) will also be longer than the corresponding phases of the early types. This would be but an instance of what Webber [1906] and Collins [1916] call physiological correlation, *i.e.*, the two characters in question ' are the result of the same physiological tendency. '

That long-flowering-duration varieties take a comparatively longer time for ripening than the early ones, has also been mentioned by K. Ramiah in *Madras Agricultural Journal*, Volume XV, 1927, pages 47-48.

VII. SUMMARY AND CONCLUSIONS

The above paragraphs discuss some of the prominent features of the rice varieties of United Provinces as regards their earliness. They are—

1. The transplanted rice varieties can be classified into two main groups, *i.e.*, early and late.

2. The broadcast varieties contain some of the earliest types, the most popular of which are the *sathi* rices.

3. In the early transplanted varieties the flowering duration has been found to be affected by the age of seedlings at the time of transplanting, increased age resulting in delayed flowering. This has been demonstrated statistically.

4. In the case of the late varieties the age of seedlings at the time of transplanting does not affect the flowering significantly.

5. In view of the fact mentioned in paragraph 3 it is suggested that where a comparison has to be made of earliness in various cultures attempt should be made to transplant seedlings of the same age by confining the transplanting operations within the shortest possible range of time if the cultures have been sown on the same date in the nursery.

6. Very much delayed transplanting in some early types has been found to result in a precocious flowering which, however, does not represent the normal flowering phase of the varieties.

7. The ripening period is shorter in the case of early varieties than in the late ones.

8. Within the same group of varieties (*i.e.*, early or late) the relation between flowering duration and ripening period is not constant and shows insignificant correlation.

REFERENCES

Allen, C. J. (1924). *J. Agric. Res.* **29**, 1—48.

Ayyangar, G. N. R. (1921). *Agric. J. Ind.* **16**, 156-168.

Biffen, R. H. (1905). *J. Agric. Sci.* **1**, 4-48.

Bryan, W. E. and Pressley, E. H. (1921). *Arizona Agric. Expt. Stn. Ann. Report (1920-21)*, 603-605.

Caporn, A. S. (1918). *J. Gen.* **7**, 247-257.

Collins, G. N. (1916). *J. Agric. Res.* **6**, 435-453.

Farrer, W. (1898). *Agric. Gaz. New South Wales* **9**, 131-168, 241-250.

Fisher, R. A. (1932). 'Statistical Methods for Research Workers,' 4th Edition, Oliver and Boyd, Edinburgh and London.

Florell, V. H. (1924). *J. Agric. Res.* **29**, 333.

Freeman, G. F. (1919). *Gen.* **4**, 1-93.

Hoshino, Y. (1915). *J. Col. Agric. Tohoku Imp. Univ. Sapporo, Japan* **6**, 229-288.

Jones, J. W. (1928). *J. Agric. Res.* 36, 581.

Ramiah, K. (1933). *Ind. J. Agric. Sci.* **3**, 377-410.

Sethi, R. L. and Saxena, B. P. (1930). *Mem. Dept. Agric. Ind., Bot. Ser.* **18** No. 6.

Thompson, W. P. (1918). *Trans. Roy. Soc., Canada*, Ser. 3-12 (Sec. 4-5), 69-87.

Webber, H. J. (1906). *Amer. Breeders' Assoc. II*, 73-83.

A PRELIMINARY NOTE ON COTTON FAILURE IN THE PUNJAB AND SOME ABNORMALITIES IN THE PLANT

BY

R. H. DASTUR,

Plant Physiologist, Agricultural College, Lyallpur (formerly Professor of Botany, Royal Institute of Science, Bombay)

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(With Plates XXIX—XXXI)

Introduction

The American cotton crop in the Punjab is subject to periodic partial failures. Such partial failures occurred in the year 1919, 1920, 1921, 1926, 1927 and 1928. The symptoms of the failures were early reddening of the leaves, bad opening of the bolls with immature seeds and low quality of lint and in the extreme cases the dwarfing of the plant. Naturally attempts were made to determine the causes of such failures of the crop in these years when the yield of seed cotton was abnormally low. Various views were advanced like the heat-storke theory of Milne [1924], unfavourable combination of climatic and soil factors by Trought [1931], attack of White-fly [Roberts, 1929], Jassid attacks and concentration of salts surrounding the feeding zones of the roots. All these theories could not be supported with sufficient scientific data. It was, therefore, thought that internal nutritional disorders were perhaps the causes of such failures resulting in abnormally low yields. So the present scheme submitted by the Punjab Agricultural Department was sanctioned by the Indian Central Cotton Committee to study the physiology of the cotton plant with a view to determine the nature of the nutritional disorder produced and the causes underlying it. It was also proposed to study the growth of the cotton plant under different conditions of temperature humidity and soil factors.

On reviewing the work done on the problem and studying the evidence collected two lines of investigations suggested themselves. During the failure years the first symptoms were the reddening and bronzing of the leaves at the reproductive stage. These symptoms were a constant feature of the crop during the failure years always at the reproductive stage. It was, therefore, considered desirable to determine if the nutritional disorder was caused by the deficiency of minerals like magnesium, manganese or iron, since it has been shown in the case of other crops like corn [Jones, 1929], tobacco [McMurtrey Bacon and Moss, 1923;

1930], [Jacobson and Swanback, 1932], [Conner, 1932], oats [Piper, 1931], soy beans [Mann, 1930], [Odland and Crandall, 1932], [Odland and Knoblauch, 1934; 1935] and many others that deficiency of any of these minerals or their unavailability due to the alkaline conditions of the soils may bring about the chlorotic condition of the leaves ultimately producing the reddening effects in some cases and reducing the yields. The difficult task was to determine the dose of such minerals per acre as such experiments had not been done before on the College Farm. However, experiments were arranged on the randomised plot basis in five replications at two places, one at the Lyallpur Farm and the other at the Risalewala Seed Farm. The results of these experiments will be communicated later, but as far as it could be judged from the condition of the crop, no significant differences in the yields under various treatments are expected.

Side by side, the complete mineral analysis of 4 F and the *desi* (Mollisoni) cotton plants at fortnightly intervals was also undertaken. The pH values of the soil at different depths before and after manuring with the minerals in the field trials described above are also being determined.

The second line of investigation that suggested itself was a study of the internal structure of the plant and a thorough microchemical examination of the tissues of the roots, stems and leaves throughout the season. By such microchemical study it might be possible to notice the changes occurring in the plant leading ultimately to malnutrition of the plant.

The microchemical investigation of the cotton plant has led to important discoveries. It will be reckoned in future an important event in the history of the cotton crop in India when the microscope was first focussed on the section of a leaf discerning the abnormal features to be described below. One by one these abnormal features came to light as the season advanced and it was found that the cotton plant is afflicted by an internal trouble not known before.

This trouble is not confined to American cottons (*G. hirsutum*) alone but is equally widespread in the indigenous types. It is the time of its incidence and its intensity that bring about such wide variations in the yields from plant to plant, field to field and season to season.

One of the main reasons why the trouble has remained unnoticed is the external green and healthy appearance of the plant, though internally ' diseased '. The indigenous types do not show any unhealthy appearance but the American types fortunately show externally the effects of this internal disease in reddening of the leaves and bad opening of the bolls. When the disease takes hold of the plant at a very early stage in the growth of the plant, these external symptoms in the American cottons may be aggravated and partial or complete failure may result. The abnormal features will be first described and an attempt will then be made to connect up these abnormalities. It may be stated here that these abnormalities found in the leaves and roots of cotton plants have not been described before for any other plant.

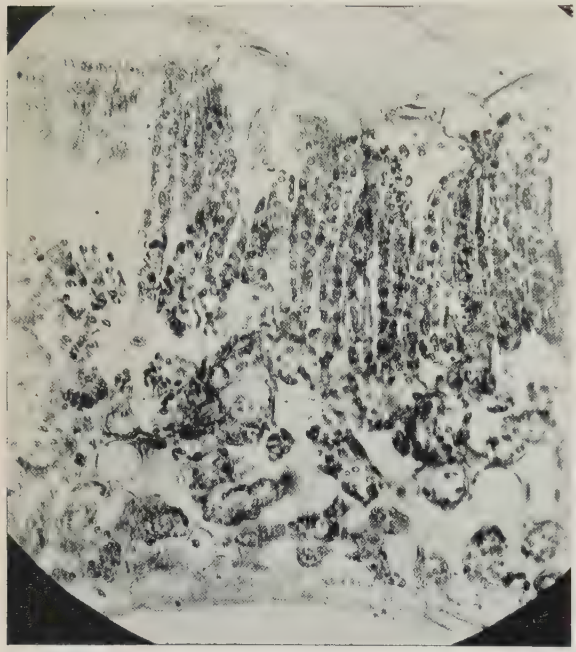

FIG. 1. Transverse section of leaf of 4-F American, showing normal chloroplasts.

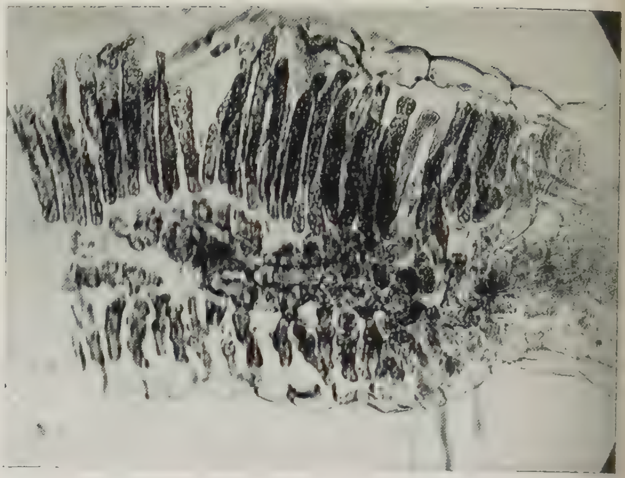

FIG. 2. Transverse section of leaf showing the disintegrated plastids.

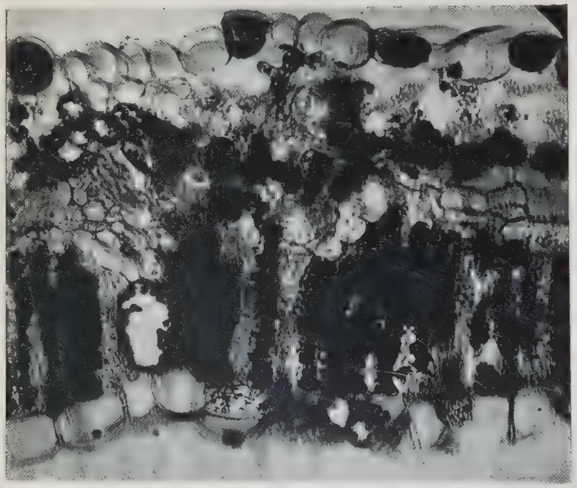

FIG. 3. Transverse section of leaf of 4-F American, showing the cells filled with yellow deposits.

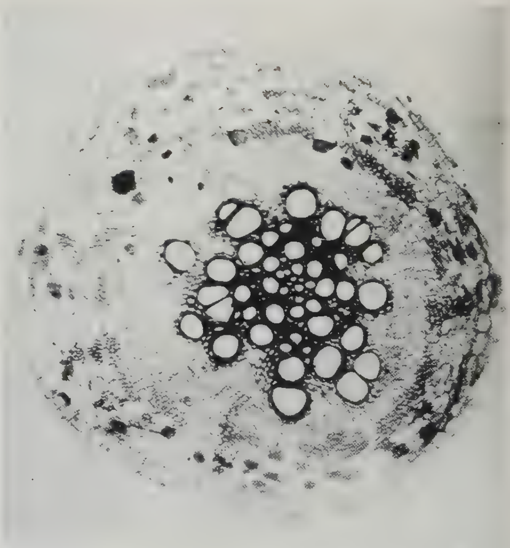

FIG. 4. Transverse section of root of 4-F American, showing the formation of colonies of particles exhibiting brownian movement.

ACKNOWLEDGMENT

I take this opportunity of expressing my deep sense of gratitude to H. R. Stewart, Esquire, Director of Agriculture, Punjab, for giving me all facilities and entire freedom to plan and to carry out this investigation in the manner I thought best. I have also to thank S. M. Nasir, Esquire, of the Punjab Agricultural College, for the bacteriological part of the investigation that he has carried out for me.

Investigation

I. ABNORMALITIES IN THE LEAVES

(1) Disintegration of the chloroplasts

In the beginning of July* while examining the tissues of the leaves of the 4-F cotton it was discovered that the green plastids in some of the palisade and spongy cells of the leaves had become broken down into small particles and in place of large egg-shaped chloroplasts arranged in parallel rows (Plate XXIX, fig. 1) the cells were filled with powdered grains (Plate XXIX, fig. 2). This observation at once struck one as being an abnormal feature; so sections of mature, healthy and green leaves were examined and it was found that in some cases all the mesophyll cells contained the plastids intact (Plate XXIX, fig. 1), in some cases some of the mesophyll cells had the chloroplasts intact, while others were broken up and in some leaves all the cells showed disintegrated chloroplasts. These three different stages in the state of plastids are hereafter termed as normal, partial and total respectively.

The leaves of different strains like the L. S. S., 43 F, 38 F, Egyptian cotton Boss III, 289 F, and 285 F were examined and similar features noted.

By the beginning of August, the number of leaves showing these disintegrated plastids increased, so much so that leaves with normal chloroplasts became rare and unusual. Towards the end of August it was not possible to find leaves with normal plastids. Even though the leaves appeared normal, healthy and green externally, yet internally they were all diseased in the sense that their photosynthetic mechanism had been thrown out of gear. In the young leaves very careful examination showed that the normal chloroplasts were absent. Whether the chloroplasts first developed and then disintegrated or did not develop at all was difficult to determine. Though the number of leaves examined every day had to be limited for want of assistance, it can be said with certainty that leaves with normal chloroplasts were rare. Plants were then obtained from fields outside the Lyallpur Farm with similar results. Plants were next examined from outside Lyallpur district but normal leaves were not found. From Shahpur district, the August specimens had leaves with normal chloroplasts but subsequent specimens obtained in September had diseased leaves. American cotton plants were obtained from Sind. In the samples sent in August, the leaves were quite normal but the samples obtained in September showed the same abnormality.

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* Crop is sown in 2nd week of May and harvested in October to December.

The search was not confined to American cottons alone but to *desi* varieties also. Disintegration of chloroplasts in the month of September was noticed in the various varieties of *desi* cottons in the Punjab, Sind, Surat, Dharwar and Indore. The following table will give an idea of the different strains of the American and *desi* cottons examined and the months in which the chloroplasts were found to be broken up. In many cases the samples could not be examined earlier than the months indicated and so it is difficult to say when the first symptoms of the trouble appeared. Thus the disintegration of the chloroplasts is not a feature confined to American cottons alone but is also a common feature of the indigenous varieties so far examined.

The leaves of Verum and Buri cottons obtained from Nagpur as late as December had normal chloroplasts. Similarly the specimens received from Ujjain at the same time had partially decomposed chloroplasts in the leaves.

(2) *Accumulation of starch in the leaves*

The accumulation of starch is another abnormal feature noticed in the leaves. It was first noticed in the 4 F plant in August. The starch grains were large and could be easily mistaken for chloroplasts. These starch grains were first mistaken for the spheres described by Sorokin [1927] in the case of tomato maosaic. Like these spheres they were soluble in ten per cent potassium hydroxide but later they were identified as starch grains. The starch grains are large and they completely fill the palisade and spongy cells. Surrounding the starch grains are found small bodies. They form a ring round the starch grains and can be easily distinguished from the starch grains by proper staining. Under normal conditions the starch grains are always found on the surface of the chloroplasts but here they lie free in the cell and completely fill them. Under normal conditions the starch grains would be hydrolised by diastases and translocated as sugars to the interior of the plant. For some reasons or the other this does not happen in these leaves.

The accumulated starch remains in the leaf even when it has turned yellow or red. Under normal conditions the functionless leaf is depleted of starch while in the case of the American cottons examined the dead leaves in some cases contain starch. It is at present difficult to state if this is a common feature of all the dead leaves of American cottons.

The greater accumulation of starch always occurs in the leaves produced earlier in the vegetative period. In the new leaves which develop later, the starch accumulation becomes less and less because the disintegrating process in the chloroplasts sets in earlier as the season advances and consequently the photosynthetic process is also inhibited earlier in the newly developed leaves. Hence starch accumulation does not occur in the leaves developed later.

(3) *Hypertrophy of the mesophyll cells*

The elongation of the palisade and spongy cells is another abnormal feature of the leaves of the American cottons which manifest itself in their crumpling, curling and thickening. The elongation of the palisade cells to nearly twice their normal length results in increasing the thickness of the leaf as a whole. The elongation of the spongy cells which is in a plane at right angles to the plane of elongation of the palisade cells increases the area of the lower surface of the leaf. Upward curling of the leaf results as the lower surface becomes greater than the upper surface. When the elongation of the palisade and the spongy cells is irregular, the leaf crumples. The elongation of the palisade cells in the leaves of the American cotton has also been noticed by Jones and Mason [1926] in two obscure diseases of cottons.

(4) *Formation of tannins and other deposists in the cells*

Later on the palisade and spongy cells of the leaves become filled with a yellowish mass. The plastids of the disintegrated chloroplasts disappear entirely and the starch grains usually disappear or are covered by the yellow substance (Plate XXIX, fig. 3). Some of the mesophyll cells as well as the conducting parenchymatous cells in the leaves become filled with small bodies which are round and yellow in colour. These bodies ultimately fuse together and give rise to a homogeneous yellow mass. In the later stages all the cells of the leaves including the conducting elements become completely filled with the yellow substance. The yellow mass gives the characteristic reactions of tannins, fats and protein substances. These yellow contents stain dark blue with Methyl violet, Gentian violet and many other vital stains. The whole section of the leaf looks like a row of dark cells easily seen under a low power microscope. The difference between an healthy leaf and the diseased leaf becomes most marked at this stage. Yet, then, the leaf may appear externally green in colour. A yellowed or reddened leaf has also similar deposists in the mesophyll cells.

(5) *Reddening of the leaves*

The reddening of the leaves is the final external symptom of the series of changes described above, and beginning weeks before the red colour appears in the epidermal cells. It is the final stage in the process of internal disintegration that occurs in the leaves. The red colour as is well known is caused by the production of anthocyanin pigments that develop in the leaves which are in the senescent stage. The acidic reaction of the cell sap gives reddish colouration to the anthocyanin pigments. There is a mixture of anthocyanins and anthoxanthins in the epidermal cells as can be seen by the change of reddish to greenish colour in the cells when they are immersed in alkaline solutions. (Anthocyanin pigments when present alone turn bluish in an alkaline medium). The production of anthocyanins in leaves of plants is closely associated with the presence of carbohydrates and this is actually the case in the leaves of cotton plant. The leaves contain starch and perhaps to some extent sugars and as they are not translocated, they give rise to anthocyanin pigments in the epidermal cells. Often anthocyanin pigments are not produced and though the green colour of the leaf is maintained, the interior of the leaf is as much destroyed as in the case of a red leaf. A plant may have greenish leaves and yet it may be as much diseased as a plant with red leaves. Reddening is not always the external indicator of the internal trouble.

To sum up briefly, the disintegration of the chloroplasts begins to occur in the leaves. The period when it first makes its appearance appears to vary from plant to plant, field to field and perhaps from season to season and place to place. It may start at any time in July to October if the seeds are sown in May, *i.e.*, two months after sowing. Thus the synthetic mechanism of the plant becomes less and less efficient as growth proceeds till it stops altogether. There is also unusual accumulation of starch in the cells of the leaves. The accumulation diminishes in the leaves that develop at a later stage. There is also an elongation of the palisade and spongy cells in different planes and this gives rise to crumpling, curling and thickening. Later tannins develop and protein substances are produced. Finally the development of anthocyanins and anthoxanthins occurs in the epidermal cells and produces reddening of the leaves. This last change does not always take place.

A list of the various strains of American and desi *cottons examined for 'internal trouble' in the leaves, roots, and stems*

Strain	Date of collection	Remarks
4F (Lyallpur) . .	Throughout the growing season	Up to June :—Free. July : —Traces August } Medium September } Later on the trouble has been progressively increasing. *Note* (1) At Lyallpur the trouble was first noticed in a serious form in squares No. 43 and 26, Agricultural Farm, Lyallpur. (2) In square Nos. 24 and 46 the plants are healthy even in November. They are green and show good opening. Only some traces of the disease are seen inside the plant.
L. S. S. (Lyallpur) .	July and August .	Medium.
289 F. (Lyallpur) . .	11th October 1935 .	Diseased.

Free = No disintegration of chloroplasts and no deposits in the cells of the roots and stems.

Medium = Disintegration of chloroplasts occurs late in the season. The deposits appear late in the roots and stems and do not extend into the medullary rays and xylem parenchyma.

Diseased = Disintegration of chloroplasts within three months after sowing and formation of deposits in all the storage and conducting cells.

A list of the various strains of American and desi *cottons examined for interna trouble in the leaves, roots and stems*—contd.

Strain	Date of collection	Remarks
38 F	September and October	Medium
47 F	4th October 1935	Do.
73 F	11th October 1935	Diseased
43 F	7th October 1935	Do.
46 F	10th October 1935	Do.
56 F	Do.	Do.
58 F	Do.	Do.
48 F	9th October 1935	Do.
72 F	Do.	Do.
2/35 P 24	8th November 1935	Medium
1/35 P 38	Do.	Do.
10/35 P 26	Do.	Do.
22/35 P 11	Do.	Do.
8/35	Do.	Do.
9/35	Do.	Do.
43/35	14th November 1935	Diseased
44/35	Do.	Do.
29/35	Do.	Do.

Cottons from other parts of the Province

Place	Strain	Date of collection	Remarks
Kalara (Shahpur)	4 F	15th Aug. 1935	Free
		15th Sept. 1935	Diseased
		15th Oct. 1935	Do.

Cottons from other parts of the Province—contd.

Place	Strain	Date of collection	Remarks
Jaranwala . . .	4 F . . .	16th Aug. 1935 .	Diseased.
		26th Aug. 1935 .	Do.
Jahanabad (Shahpur) .	4 F . . .	14th Aug. 1935 .	Do.
Chak Dora (Shahpur) .	4 F . . .	15th Aug. 1935 .	Medium
Chak 109 R. B. . .	4 F . . .	5th Sept. 1935 .	Do.
Chak Branford (Lyallpur)	4 F . . .	10th Sept. 1935 .	Diseased
Narwala (Lyallpur) .	4 F . . .	20th Sept. 1935 .	Medium
Sharakpur . . .	4 F . . .	26th Sept. 1935 .	Diseased
Raewind . . .	4 F . . .	7th Oct. 1935 .	Do.
Chak 223 (Lyallpur) .	4 F . . .	24th Oct. 1935 .	Do.
Ganga-nagar (Jaranwala)	4 F . . .	5th Oct. 1935 .	Do.
Do. .	L. S. S. . .	Do. .	Do.
Chillianwala (Gujrat) .	L. S. S. . .	26th Sept. 1935 .	Medium
Do. .	38 F . . .	Do. .	Diseased
Do. .	45 F . . .	Do. .	Do.
Do. . .	4 F . . .	Do. .	Do.
Khanewal . . .	4 F . . .	25th Sept. 1935 .	Medium
Do. . . .	K. T. 23 . .	Do. .	Diseased
Do. . . .	K. T. 25 . .	13th Oct. 1935 .	Do.
Do. . . .	38 F . . .	Do. .	Do.
Multan . . .	43 F . . .	3rd Nov. 1935 .	Do.
	4 F . . .	Do. .	Do.
	38 F . . .	Do. .	Do.
	L. S. S. . .	Do. .	Do.
	73 F . . .	Do. .	Do.

Cottons from other parts of India

Place	Strain	Date of collection	Remarks
Sakrand (Sind)	4 F 98	10th Aug. 1935	Free
	289 F	Do.	Do.
	Do.	3rd Oct. 1935	Diseased
	4 F 98	Do.	Do.
	289 F	25th Sept. 1935	Do.
	Cambodia	14th Oct. 1935	Do.
	4 F 18 Parent	1st Nov. 1935	Do.
	4 F 18 × Meade Strain No. 94	Do.	Do.
	4 F 18 × Meade Strain No. 101	Do.	Do.
	4 F 18 × Meade Strain No. 27	Do.	Poor medium
	Meade parents	Do.	Diseased
	Sea Island × 285 F	Do.	Do.
	Do.	Do.	Do.
	185 F_2	Do.	Do.
	4 F 98	Do.	Do.
	A, 2 Bulk.2-45	Do.	Do.
	2-26-41	Do.	Do.
	Boss III 16	Do.	Do.
	Ashmoni 39	Do.	Do.
	C o II	Do.	Do.
	N. T. 21-8-8	Do.	Do.
	K. T. 25-81-5	Do.	Do.
	Desi 27 W.N.	Do.	Poor medium

After the paper was sent for publication many other strains of cotton have been examined with similar results.

Cottons from other parts of India—contd.

Place	Strain	Date of collection	Remarks
Surat . . .	1027 A.L.F. . .	15th Aug. 1935 .	Medium
	Do. . .	7th Oct. 1935 .	Diseased
Nagpur . .	Buri . . .	25th Oct. 1935 .	Free
	Verum . . .	Do. .	Do.
Indore . . .	Malvi 1 . . .	29th Oct. 1935 .	Diseased
	Malvi 9 . . .	7th Sept. 1935 .	Free
	Do. . . .	29th Oct. 1935 .	Diseased
	Cambodia . . .	30th Oct. 1935 .	Do.
	Co II (Coimbatore) .	Do. .	Do.
	(Sanguineum × Sea Island) × $_2$U Upland	Do. .	Medium
Dharwar . .	102 E . . .	3rd Nov. 1935 .	Do.
	Gadag × 102 E . .	Do. .	Do.
	Gadag 1 . . .	Do. .	Do.
	Jaywant . . .	Do. .	Diseased
	Dharwar 1 . . .	Do. .	Do.
Parbhani . .	American No. 1 . .	8th Oct. 1935 .	Free
Ujjain . . .	Cambodia . . .	26th Oct. 1935 .	Do.

Indigenous cottons of the Punjab

Strain	Date of collection	Remarks
G. indicum var. *Mollisoni*	Throughout season	Free up to July and August. Then some plants medium, others free from disease.
G. indicum proper	26th Sept. 1935	Medium. Only cortex is affected. Medullary rays are all free.
G. neglectum proper	Do.	
G. neglectum var. *Rosea*	Do.	
G. sanguineum		
Var. *Major*		
(*i*) Broad-lobed	Do.	
(*ii*) Narrow-lobed	Do.	
Var. Minor		
(*i*) Broad-lobed	Do.	
(*ii*) Narrow-lobed	Do.	

Plants other than cotton examined for the disease

Plant	Date of collection	Remarks
Ocimum sanctum	8th Oct. 1935	Free
Vinca rosea	Do.	Do.
Hibiscus esculentus	15th Oct. 1935	Very slight tendency towards disease
	6th Nov. 1935	
H. rosasinensis	2nd Nov. 1935	Free
Abutilon indicum	17th Oct. 1935	Do.
	2nd Nov. 1935	Do.
Hollyhock and many others	1st Nov. 1935	Do.

II. ABNORMALITIES IN THE ROOTS

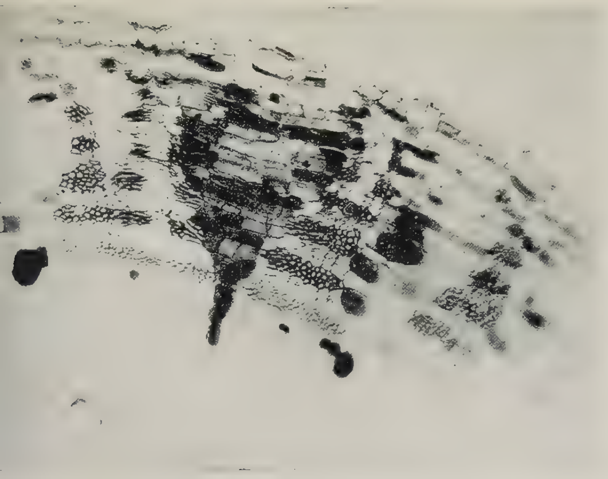
Many abnormal changes take place in the roots from the very seedling stage up to the time of maturity and in order to differentiate these changes from one another fresh material and sectioning are necessary. Only a very careful and prolonged study under the microscope has revealed the important and intricate changes which take place in the interior of the roots.

In the seedling stage the first symptom to be noticed is the brownian movement of the very small particles which give the appearance of small organisms (Plate XXX, fig. 4). They do not stop moving when treated with osmic acid and are not stained with iodine. These particles are seen to aggregate into cells and form a colony which is covered with a yellow mucilagenous mass (Plate XXX, fig. 4). These yellow masses can be easily distinguished under the low power of the microscope. When treated with an alkali, the yellow mass dissolves away but the particles still persist and exhibit brownian movement. These bodies when treated with nitric acid appear yellowish in colour. They are not soluble in strong nitric or hydrochloric acid. These yellow colonies become enlarged and assume a darker colour than before as the roots grow older. They are generally situated in the cortical region of the roots but are also found in the phloem. In a cross-section of the roots a number of them can be seen. The number continuously increases as the roots grow in thickness.

The second important change which takes place in the roots is the formation of some deposits in the cells of the cortex and the phloem (bark). These deposits are not seen in fresh sections but become apparent in stained preparations (Plate XXIX, fig. 4). They do not dissolve in alkalies or acids. They give all the protein reactions. They stain black with osmic acid. They are stained with all aniline stains like Methyl violet, Methylene blue, Giemsa and Lieshman's stains (Plate XXX, figs. 1 and 2).

These colourless deposits also gave all the colour reactions of tannins. About ten different colour reactions for tannins have been obtained with these deposits.

The number of cortical cells containing these deposits increases as the plant advances in age so much so that the whole tissue of the bark except the bast fibres becomes filled with it. The formation of these deposits then extends into the medullary rays and the xylem parenchymatous cells surrounding the vessels (Plate XXX, fig. 2). The vessels are free of these deposits except in some rare cases. Thus all the conducting channnels of the roots for the translocation of the elaborated foods and the storage places are filled with substances which appear to be a mixture of proteins, fats and tannins.



. Transverse section of root of 4-F American, showing the complex deposits in the cortical cells.

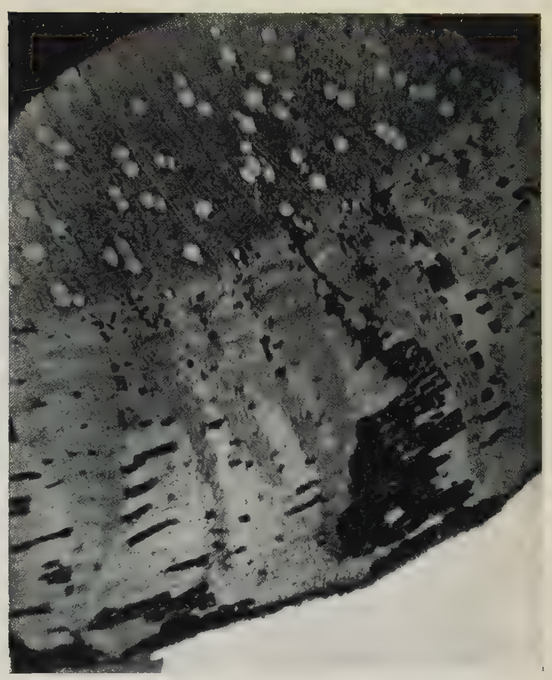
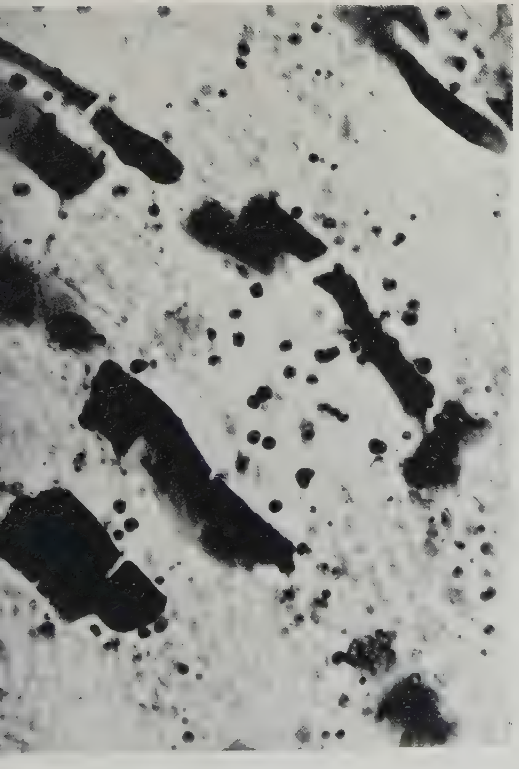


Fig. 2. Transverse section of root of 4-F American, showing deposits in the cortical cells, phloem, medullay rays, and xylem parenchyma.



3. Transverse section of root, showing the formation of the complex deposits.

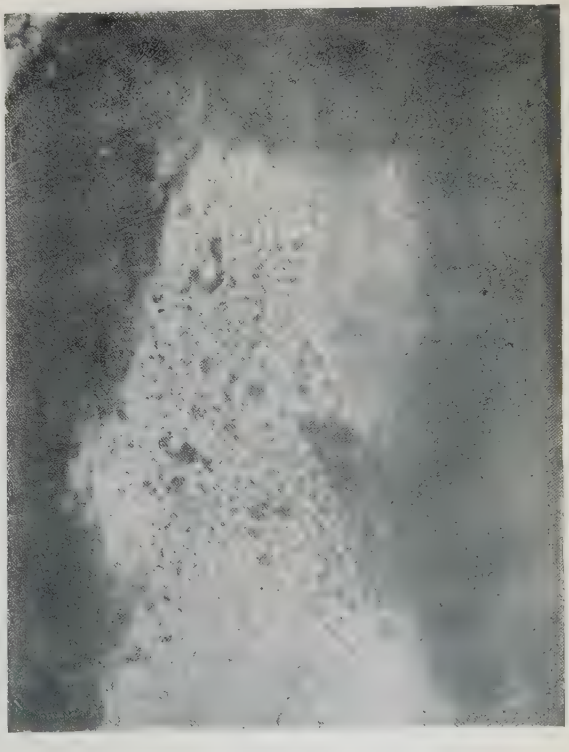


Fig. 4. A yellow colony with particles exhibiting brownian movement.

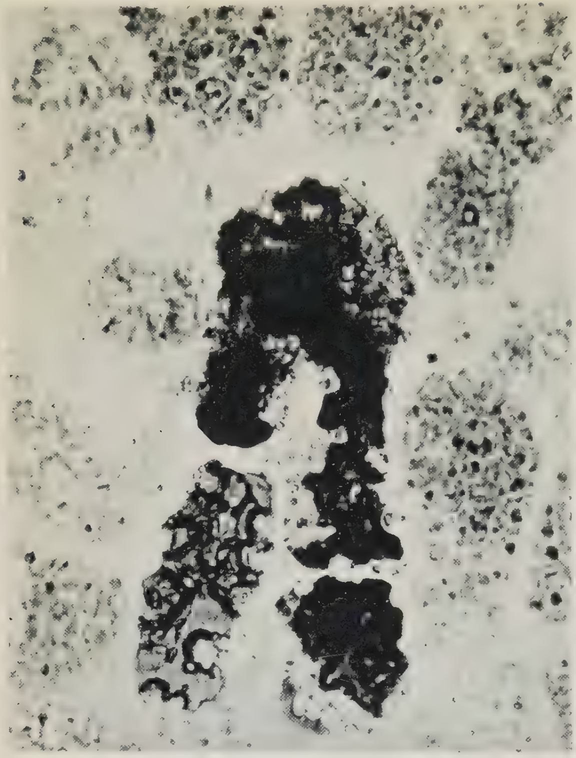


FIG. 1. Transverse section of root, showing semi-liquid deposits on the starch grains inside the cells of the root.

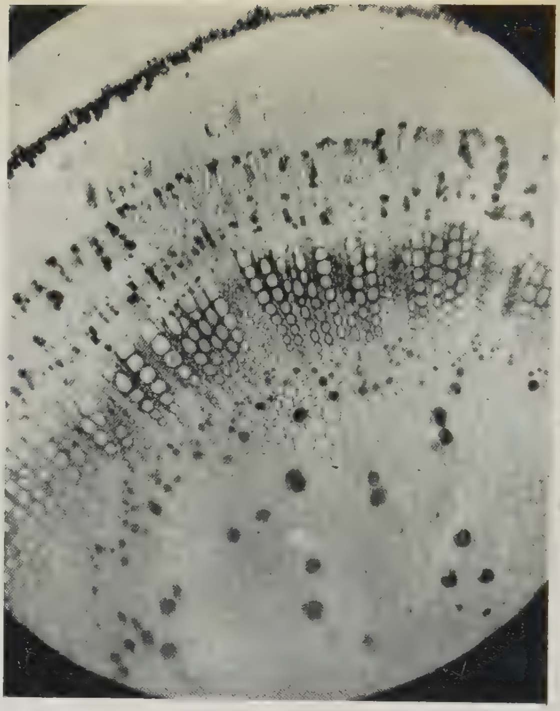


FIG. 2. Transverse section of stem of 4-F American, showing deposits in the epidermis, phloem, medullary rays and pith.

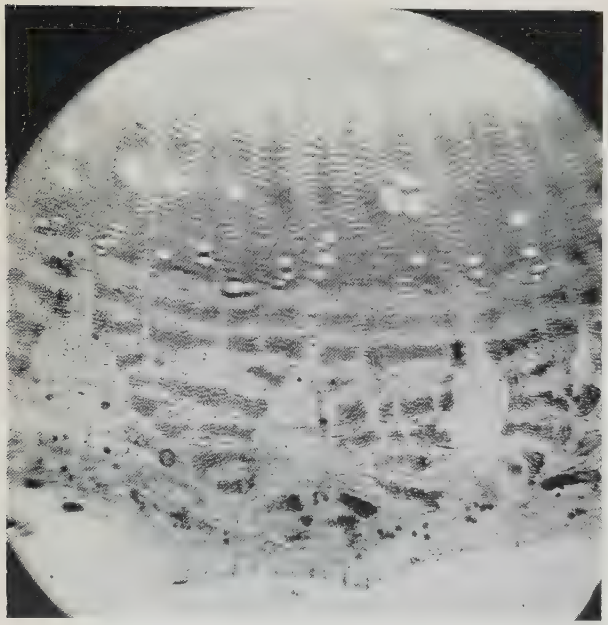


FIG. 3. Transverse section of roots of 4-F American, of a well-opened plant showing the absence of deposits.

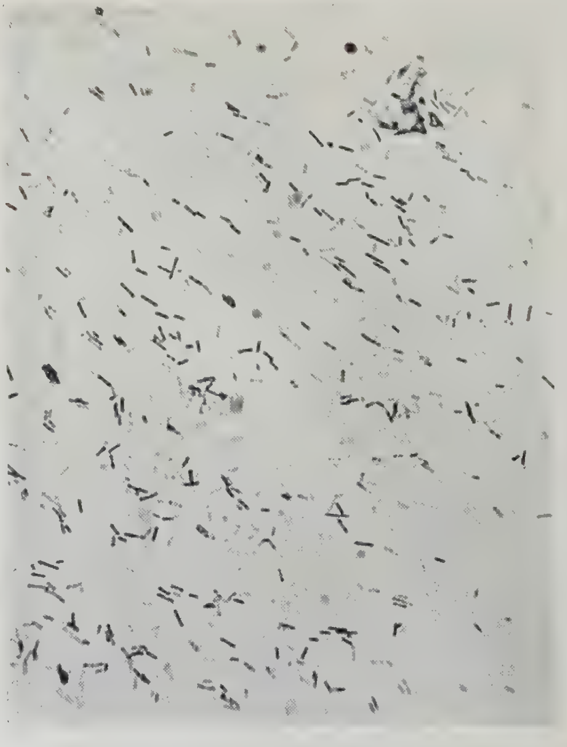


FIG. 4. The bacteria cultured from the embryo of 4-F American seed.

Similar deposits are also found in the lower portions of the stem (Plate XXXI, fig. 2) and the trouble extends upwards into primary and secondary branches. They can be seen in the topmost parts of the plant including the pericarp of the bolls. Sometimes the upper parts of the stem and branches are free while the lower parts of the same plant show these deposits.

These deposits found in the cells of the bark, the medullary rays, and the other cells are seen to develop from the particles exhibiting the brownian movement. These particles aggregate and form a small or a big colony which ultimately loses its granular character and appears as a semi-liquid mass. If the cell in which this process occurs contains starch grains, the fluid mass envelopes them (Plate XXX, fig. 3, and Plate XXXI, fig. 1). Later some reaction between the starch grains and the substance of the mass occurs and the starch grains lose their shape and character and a complex deposit described above is formed. This process occurs all along the storage and the food conducting cells of the plant.

In some cases the small particle surrounds the starch grain (Plate XXXI, fig. 1) and transforms the latter into a yellow body. Though the original shape of the starch grain is retained it does not stain with iodine. The transformed body of the starch is then stained with Methyl violet like the deposits described above, giving protein reactions.

Another abnormality found is the large accumulation of starch in the cortex, medullary rays, the xylem parenchyma and the pith. In many cases the roots and lower parts of the stems are completely filled with starch grains.

It was observed that, as in the case of the leaves, the time at which these abnormalities begin to appear in the bark of the roots and stems varies from plant to plant and filed to field. In some cases it was noticed in the month of July while in others in August or September or even later.

These abnormalities in the roots and stems were noticed only to a small extent or were entirely absent in plants which had well-opened bolls (Plate XXXI, fig. 3) while they were always present to a very great degree in badly-opened plants in the Punjab.

The following evidence indicates that the formation of these deposits in the roots and stems is an abnormal feature of the cotton plants here. (1) The deposits are not found ordinarily in plants either allied to cotton or plants belonging to other families. (2) It is possible to find cotton plants which do not show these abnormalities. The Verum and Buri cottons from the Nagpur Farm are free of these abnormalities even at harvest time. (3) 4-F cotton plants are also found in which these abnormalities are absent even at harvest time. (4) The period at which they appear varies from plant to plant. If it is a regular feature they should begin to appear at almost the same time at least in the same field in plants grown from seeds sown at the same time.

The great accumulation of starch at the fruiting stage in the roots and stems is also abnormal at the time when the starch should be hydrolysed and translocated to the fruiting parts. In plants whose bolls are opening well no such accumulation is noticed. In badly-opened plants the accumulation of starch is found to occur in roots, stems and branches.

The formation of these abnormal deposits is found in almost all varieties of cottons whether exotic or indigenous (Table I). It is most conspicuous in the Egyptian and American cottons grown in India. In *desi* cottons the formation of these deposits begins late in the season and is not so vigorous in most cases.

III. PRESENCE OF MICRO-ORGANISMS

Chloroplasts are stable bodies and though the green colouring matter adsorbed on their surface decompose, they are not ordinarily broken down to particles. The disintegration of chloroplasts in a healthy plant cannot occur except by the action of proteolylic enzymes secreted by micro-organisms present in the plants. Such disintegration of chloroplasts in leaves is reported by Sorokin [1927] and Eckerson [1926] in the case of tomato mosaic. It was, therefore, undertaken to determine whether any micro-organisms like bacteria or protozoa are present in the cotton plant.

Attemps were made in the first place to culture the organism from the leaves and it was found that rod-shaped bacteria in pure colonies developed in the culture media. These bacteria are different from *B. malvacearum* which causes the Black Arm disease of cotton. They have flagellae on all sides, while *B. malvacearum* has only one flagellum. Similar organisms were obtained from the root cultures.

Attempts were made to obtain bacterial cultures from the 4 F seed and it was found that the embryos in the seeds were infected, as the same form of bacteria developed from the seed cultures (Plate XXXI, fig. 4).

Later the seeds of the different strains of exotic and indigenous cottons were examined and these micro-organisms were found in each case. The cultures were made in duplicate.

These organisms have also been cultured from the old roots of cotton plants of the previous season and they are also found in abundance in the roots of *toria* which is a rotational crop with cotton in the Punjab.

Discussion

There are thus three principal types of abnormalities. (1) Disintegration of chloroplasts. (2) Formation of deposits in the bark and other conducting tracts with the accumulation of starch in diseased plants and (3) Presence of organisms in all parts of the plants.

It is well known that when pathogenic bacteria are present in a plant, changes of a chemical nature are produced by them in the host. They are known to produce injurious acids and toxic substances which inhibit physiological activities. On the other hand they also help the production of substances which stimulate the cell activities and either the multiplication or an increase in dimensions of the cells occurs.

In the cotton plant three effects of the presence of the pathogenes on the plant body are visible : (1) Hypertrophy of mesophyll cells, (2) Disintegration of chloroplasts and (3) Abnormal production of cell deposits. Even though the bacteria are present, the cotton plant offers great resistance to them and the plant does not succumb to them.

It may be tentatively concluded that the first two abnormalities result from the presence of bacteria in some form of their life-cycle though at present no definite demonstrative evidence to show that the organisms actually cause them* exists. The presence of organisms is now definitely established and cannot be disputed. It can be cultured in twenty-four hours from every part of the plant body. The novel feature is that when plant material is examined fresh, no living organisms are seen but they appear only after twenty-four hours when the sections of the root are left in sterilised water or kept in culture media*.

The chloroplasts of the leaves may suffer disintegration due to the toxins or proteolytic enzymes secreted by the bacteria. This has been verified by leaving a section of the leaf in hanging drop of water on a slide and infecting it with bacteria. By this means disintegration of plastids was obtained. This must be verified again as it was not possible to get a normal leaf free from this trouble and hence it cannot be said definitely whether the disintegration is actually caused by these organisms or not.

Secondary infection very probably occurs through the soil either from the ungerminated seeds, the old roots of the cotton plant of the previous season or from the roots of rotational crops especially the roots of *toria* which abound in these organisms. As a result of infection whether primary or secondary, pathological conditions result and these cell deposits are produced. It may be argued that the deposits produced in the cells may only be plastic material just like starch and are not produced as a result of patholocical condition. This appear unlikely as no such production of deposits occurs in cotton plants that grow normally and open well. They should also disappear when the bolls mature, but this does not happen. The cells contain them even after the plants have produced bolls.

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* After this paper was sent for publication, the presence of the organism both inside the seed and the plant is definitely established It is also established that the complex cell deposits in the roots and stems are produced by the organism. A paper embodying these results and clarifying many points mentioned in this paper will soon be offered for publication.

These complex deposits remain in the cells as they are not translocated and also block up the normal channels of conduction.

The decomposition of chloroplasts in healthy leaves means a cessation of photosynthetic activity. The chloroplasts are the most important bodies in the life of a plant, as they are seats of all synthetic processes by which the food of the plant is manufactured. If they are gradually decomposed as the plant grows, less accumulation of food for the reproductive phase results.

In a normal plant all food, carbohydrates and proteins, which is manufactured by the leaves, is stored up in the storage tissues of the stems and roots. This accumulated food travels upwards in solution during the fruiting stage and is ultimately deposited in the seeds. The abnormal features in the roots and stems of the cotton plant described above do not permit of the translocation to the developing bolls of the food stored in these organs. The starch is also not hydrolysed and so cannot travel upwards. Most of it is used for the formation of complex deposits and so it is lost to the plant. Proteins are also precipitated and so are not available. Naturally those bolls which do not get proper nourishment do not develop well, its seeds remain empty and small and the lint has neither the required length nor strength. Whether a boll will open well or badly, depends upon the flow of nourishment to it. The number of well-opened bolls on a ‘ diseased ’ cotton plant will, therefore, depend on the time when the disease starts. If the trouble starts early in the season the whole plant fails badly.

The very wide variations in the yields of seed cotton from fifteen or twenty maunds to four or even two maunds per acre that are obtained in the Punjab on good soils and even in the same fields may now be more clearly understood than before on the basis of this internal trouble. These variations depend on the time of the incidence and the intensity of the ‘ disease ’. It is also likely that other conditions of the soil and climate may have some effect on the intensity of the disease and time of its appearance in the plant. This will be investigated now.

Red-leaf disease

The reddening of the leaves of American cottons was first reported by Butler [1908] and then by Burt and Nizamuddin [1919]. Since then the term Red-leaf disease has come into use. In view of what is stated above, the reddening of the leaf is due to secondary changes in the leaf after it has ceased functioning. The reddening may occur at the normal cessation of the functional activity of the leaves. The premature reddening of the leaves is caused by the premature death of the leaves and for this reason such reddening of the leaves may be regarded as the external symptom of the internal disease. But it is also noticed that reddening of the leaves may not occur at all even though the plant is diseased and opens badly. Innumerable American cotton plants which have green leaves but which are diseased and have opened badly have been observed. Reddening of the leaves should not be regarded as a true indicator of the internal trouble. A plant with reddened leaves may open better than a plant with green leaves if the reddening is of the normal character. The term Red-leaf disease in connection with the 'disease ' under investigation should now be discontinued. In indigenous cottons, the reddening of the leaves does not occur in any marked degree even though the same trouble exists there.

It is clear from the results of these investigations that the abnormalities described above are not confined to the exotic cottons but are found in indigenous cottons as well. As no bad opening is noticed in indigenous cottons, one might be led to infer that these abnormalities are not the cause of the bad opening in American cottons. In the case of *desi* cottons the trouble starts later in the season and conduction of food substances is not as much impeded as in the case of American cottons. No accumulation of starch in the plant is, therefore, noticed in the former. As sufficient nourishment is available for the remaining bolls, no bad opening occurs. In the case of American cottons sufficient nourishment is not available for all the bolls that remain on the plant and bad opening takes place, its extent depending on the time of incidence and intensity of the disease. It may be regarded as a fortunate occurrence that American cottons showed these external symptoms of premature reddening of the leaves and bad opening of the bolls, otherwise this internal trouble would have been left still undiscovered.

Conclusions

It is safe to conclude that these abnormalities in the American cotton are the cause of the bad opening of the bolls through want of nourishment. Though bad opening of bolls occurs in a greater or less degree in different years, the bad opening of bolls is always present. The cotton crop in the Punjab in the present season is reported to be normal but there is not a single field, as far as has been observed, which is free from plants showing bad opening of the bolls. In some fields the proportion of badly-opened bolls is very high and includes the whole crop ; in others it is low.

These badly-opened plants in most cases are neither small nor undersized so far as their vegetative growth is concerned and, therefore, the question of the deficiency of nitrogen in the soil does not arise. It is also noticed that a very small plant much below normal has very well-opened bolls if it is not diseased, while a tall and vigorous plant may have all its bolls badly-opened. Bolls smaller in size than the average, have been observed to open well if the proper nourishment is available, whereas large bolls in ' diseased ' plants crack and open badly.

The yield of seed cotton in American and indigenous cottons is less than it would be if these abnormalities of the leaves and roots did not exist. It is possible that the low yields in India as compared to other countries may be partly due to this internal trouble.

Summary

Micro-chemical study of American cottons grown in the Punjab and other places in India has revealed some very abnormal features, not noticed before.

Disintegration of the chloroplasts, in green and healthy-looking leaves first begins to occur. The time when it first begins appears to vary from plant to plant. This is followed by an accumulation of starch in the mesophyll cells. These cells also suffer elongation in different planes and this gives rise to crumpling, curling and thickening of the leaves. Later, the cells become filled with yellowish deposits which give reactions of tannins, fats and proteins. Development of anthocyanins and anthoxanthins occur in the epidermal cells and produces reddening of the leaves.

In the cortex of the roots small, yellow masses first appear. Each yellow mass contains minute bodies which exhibit rapid brownian movement. Such minute bodies have also been noticed in the cotyledons of the seed and the foliage leaves. These bodies aggregate in the cortical, phloem and other conducting parenchymatous cells and first form small or large colonies which later lose their granular appearance, and become semi-liquid in nature. These bodies react with the starch grains in the cells of the cortex, pith medullary rays and xylem parenchyma and ultimately form complex deposits of substances which give the reactions of proteins, fats and tannins. Such deposits are produced in all the cells, except the xylem vessels of the roots, stems and branches.

Micro-organisms in the form of bacteria have been cultured from either the leaf, stem, root and the embryo of the seed of the plant. They are different from the organism that causes the Black-arm disease of cotton.

These abnormalities are found in more than fifty different strains of cottons, exotic or indigenous so far examined. There are also a few strains which are free of them.

In well-opened American plants the abnormalities in the roots and stems are absent.

It is tentatively put forward that the presence of the micro-organism, in some stage in its life-cycle, is responsible for the destruction of the chloroplasts and consequent inhibition of the food-manufacturing processes of the plant. Whatever food that is stored in the roots and stems of the plant during its vegetative period, is mostly used in the formation of the complex deposits in the storage and conducting tissues and the remaining portion is not able to translocate rapidly to the developing bolls in the fruiting stage on account of the blocking up of the conducting elements by the same deposits. The bolls thus suffer want of nourishment, crack prematurely and contain immature seeds with poor lint. The number of well-opened bolls on the plant and consequently its yield depend on the time the ‘ trouble ’ starts and its intensity.

REFERENCES

Burt, B. C. and Nizamuddin Haider (1919). *Agric. Res. Inst. Pusa Bull. No.* 88.

Conner, S. D. (1932). *J. Amer. Soc. Agron.* **24**, 9,726.

Eckerson, S. (1926). *Bot. Gaz.* **81**, 204-209.

Jacobson, H. G. M. and Swanback, T. R. (1932). *J. Amer. Soc. Agron.* **24**, 237.

Jones, J. P. (1929). *J. Agric. Res.* **29**, 873.

Jones, G. H. and Mason, T. G. (1926). *Ann. Bot.* **40**, 160.

Knoblauch, H. C. and Odland, T. E. (1934). *J. Amer. Soc. Agron* **26**, 609.

Mann, H. B. (1930). *Soil Sci.* **30**, 117.

MacMurtrey, J. E.; Bacon, C. W. and Moss, E. (1923). *J. Agric. Res.* **23**, 27, 40.

Milne, D. (1924). Report, Punjab Govt. Printing Press, Lahore.

Odland, T. E. and Crandall, F. K. (1932). *J. Amer. Soc. Agron.* **24**, 622.

Odland, T. E. and Knoblauch, H. C. (1935). *J. Amer. Soc. Agron.* **27**, 216.

Piper C. S. (1931). *J. Agric. Sci.* **21**, 763.

Roberts, W. (1929). *Agric. J. Ind.* **24**, II.

Sorokin, H. (1927). *Phytopath.* **17**, 363.

Trought, T. (1931). *Ind. J. Agric. Sci.* **1**, 310.

DEVELOPMENTAL VARIATION IN THE PADDY GRAIN

BY

U TIN (1), DIP. AGRI.,

Senior Agricultural Assistant, Agricultural College, Mandalay

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CONTENTS

PAGE.

I. INTRODUCTION 396
II. METHOD OF GRAIN MEASUREMENT 397
III. SIZE OF SAMPLE 397
IV. VARIATION WITHIN A PANICLE 401
V. VARIATION BETWEEN PANICLES OF ONE PLANT 403
VI. DIFFERENCE IN VARIABILITY BETWEEN DIFFERENT STRAINS OF THE SAME CLASS 408
VII. DIFFERENCE IN VARIABILITY BETWEEN PURE LINES OF DIFFERENT CLASSES 410
VIII. EFFECT OF SPACING ON GRAIN SIZE AND VARIABILITY . . . 412
IX. EFFECT OF HARVESTING DATES ON GRAIN SIZE. 414
X. EFFECT OF SEASON ON GRAIN WEIGHT 416
XI. EFFECT OF SEASON ON GRAIN LENGTH 418
XII. EFFECT OF MANURE ON GRAIN WEIGHT 419
XIII. EFFECT OF MANURE ON GRAIN SIZE 444
XIV. EFFECT OF MANURE ON THE DIFFERENT PARTS OF THE PADDY GRAIN 448
XV. DIFFERENCE IN GRAIN SIZE DUE TO LOCALITY 451
XVI. DISCUSSION 456
XVII. SUMMARY 458
REFERENCE 459

I. INTRODUCTION

The classification of paddy on grain dimensions has engaged the attention of various workers in recent years. Beale [1927] and Sethi [1930] found that the grain-size characters are the least influenced by environment, and they therefore based their system of classification on the grain dimensions. In addition to the advantage of the stability of the grain dimensions classification based on these corresponds largely with commercial grading. Recently Ramiah [1933] found that grain size is to some extent affected by seasonal variations.

The dimensional characters of the grain have also been utilised in determining the purity of strains, as according to Ramiah [1933] these do not vary to any appreciable extent within a pure line. This is not in accordance with the statements of van der Stok [1912], who found that even within a pure line size and weight of the grains depend upon the size of the panicle and the fertility of the soil. Although the variations which occur will never be of sufficient magnitude to invalidate a system of classification based thereon, there has not hitherto appeared any reliable study of the magnitude of these variations and of the degree of variability which may be expected under different conditions. Further, in the study of the inharitence of grain-size characters a knowledge of how grain dimensions may vary in a non-inherited manner is desirable.

II. METHOD OF GRAIN MEASUREMENT

The measurement of grains by a screw gauge is a tedious and clumsy method. Throughout this investigation all measurements have been made with a special seed-measuring apparatus supplied by Messrs. Gallenkamp & Co., Ltd., London. This instrument is graduated in centimeters and millimeters and reads direct on a dial to 0·1 mm. and by estimation to 0·05 mm. When suitably held in a retort-stand clamp it is possible to carry out measurements accurately and rapidly. Unless the statistical examination of the results requires it, the individual readings are not written down. When a frequency distribution suffices, a series of small beakers each marked with its appropriate class interval is arranged on the bench and as each grain is measured it is put into the appropriate beaker. When the required number of grains has been measured the number in each beaker gives the frequencies in each class.

III. SIZE OF SAMPLE

Ramiah differs in opinion from Lord [1929] as regards the size of sample required to give a reliable result. The latter concluded that a minimum of twenty grains was necessary, while Ramiah who has restricted his measurement of the sample to the top and middle portion of the panicle has found a six-grain sample satisfactory for inheritance studies. But in the present investigation it has been found that to be representative a random sample must consist of at least 100 grains.

Five hundred grains of the pure line *Kabaing Taungdeikpan* B 30-104 were taken at random and measured and means, standard deviations, etc., for grain length were determined separately for different sizes of sample. The results are given in Table I.

TABLE I

(a) *Twenty-five-grain sample*

No.	Mean (mm.)	S. E. of mean	Variance of mean	S. E. of mean of all samples	Degrees of freedom	Sum of squares	Mean square	½ $\log_e$ (mean square)
1	8·520	0·049929	0·0024928	0·07287	24	1·4360	0·05983	0·8945
2	8·576	0·070000	0·0049000		24	2·8224	0·11760	1·2323
3	8·584	0·064949	0·0042183		24	2·4298	0·10124	1·1574
4	8·536	0·068520	0·0046950		24	2·7043	0·11268	1·2110
5	8·592	0·053647	0·0028780					
6	8·424	0·101370	0·0102760					
7	8·582	0·062724	0·0039345					
8	8·536	0·092384	0·0085350					
9	8·560	0·067840	0·0046023					
10	8·584	0·069630	0·0048484					
11	8·360	0·079968	0·0063948					
12	8·432	0·058454	0·0034070					
13	8·552	0·070876	0·0050234					
14	8·400	0·060883	0·0037068					
15	8·480	0·076630	0·0058721					
16	8·528	0·082240	0·0067634					
17	8·536	0·072160	0·0052071					
18	8·504	0·079260	0·0062820					
19	8·504	0·067960	0·0046185					
20	8·456	0·047300	0·0022373					

(*b*) *Fifty-grain sample*

No.	Mean (mm.)	S. E. of mean	Variance of mean	S. E. of mean of all samples	Degrees of freedom	Sum of squares	Mean square	½ Log$_e$ (mean square)
1	8·548	0·042883	0·0018389	0·051045	49	4·4153	0·09011	1·0993
2	8·560	0·047637	0·0022693		49	5·4487	0·10982	1·1981
3	8·412	0·050384	0·0025389		49	6·0961	0·12441	1·2588
4	8·540	0·055635	0·0030953		49	7·4320	0·15167	1·3596
5	8·582	0·048638	0·0023656					
6	8·386	0·051330	0·0026346					
7	8·476	0·047434	0·0022499					
8	8·504	0·054601	0·0026570					
9	8·520	0·045579	0·0020774					
10	8·480	0·041536	0·0017252					

(*c*) *Hundred-grain sample*

No.	Mean (mm.)	S. E. of mean	Variance of mean	S. E. of mean of all samples	Degrees of freedom	Sum of squares	Mean square	½ Log$_e$ (mean square)
1	8·554	0·030580	0·0009351	0·039582	99	9·1630	0·09255	1·1147
2	8·526	0·040920	0·0016744		99	16·4110	0·16577	1·4041
3	8·484	0·035482	0·0012589		99	12·0590	0·12180	1·2500
4	8·490	0·036134	0·0013056		99	12·7930	0·12926	1·2785
5	8·500	0·033060	0·0010930					
	8·510	0·016055	0·0002578		499	64·4200	0·12909	1·2791

Mean of 500 grains . . . . =8·510

Standard error of mean . . . . =0·016055

Variance of mean . . . . =0·0002578

From the above tables it can be seen that in many cases of the twenty-five grain and fifty-grain samples the differences of the means are statistically significant but in the hundred-grain samples no two means differ from each other with certainty. Further, the general mean of 500 grains being 8·510 mm. and the S. E. 0·016, a representative sample should have a mean lying between the limits 8·478 and 8·542 mm. Out of twenty twenty-five grain samples twelve have means outside these limits; out of ten fifty-grains samples seven have their means outside these limits, but only in one case is a hundred-grain sample outside the limits. On these grounds it is considered that a sample of hundred grains can always be relied on to give a representative reading and were it not for practical difficulties larger samples would appear desirable.

The extent of variability is an important character in grain, because uniformity in grain size conduces to lower breakage in milling and a smaller portion of unhulled grains passing the huller. When the variability between the first four samples of each size in Table I is compared, it is seen that although variability does not differ significantly between samples of the same size, yet they differ in two cases between samples of one size and another.

Table II

*Values of S. D. of z**

(*a*) *Within the groups*

	Within 25-grain sample	Within 50-grain sample	Within 100-grain sample
$\sqrt{\frac{1}{n}}$ . .	0·2040	0·1428	0·1005
$\sqrt{\frac{1}{n}}$ . .	0·4080	0·2856	0·2010

---

[*] The validity of distribution of z for the comparison of several groups is here assumed to be for a random sample from a homogenous population.

(b) Between the groups

	Between 1st and 2nd groups	Between 1st and 3rd groups	Between 2nd and 3rd groups	Between total and first group	Between total and second group	Between total and third group
$\sqrt{\frac{1}{}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}$	0·1761	0·1577	0·1235	0·1476	0·1058	0·07778
${}^{2}\sqrt{\frac{1}{2}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}$	0·3522	0·3154	0·2470	0·2952	0·2116	0·15556

IV. VARIATION WITHIN A PANICLE

Six panicles of the same plant of the pure line *Ngasein C2104* were roughly divided into three parts of equal lengths and the frequency distributions of the grain lengths for each part, top, middle and bottom, are given in Table III.

TABLE III

Frequency distributions of portions of panicles of Ngasein 2104

Classes	Panicle No. (*a*)			Panicle No. (*b*)			Panicle No. (*c*)			Panicle No. (*d*)			Panicle No. (*e*)			Panicle No. (*f*)		
	T	M	B	T	M	B	T	M	B	T	M	B	T	M	B	T	M	B
Unfilled grains . .	3	3	14	2	11	11	0	15	27	1	8	7	3	7	10	1	8	22
7.2 . . .	0	2	3															
7.4 . . .	0	3	2		1	1												1
7.6 . . .	1	1	4		2	1		1			1	2						1
7.8 . . .	3	3	5			1		3	1	1	3	1	1					2
8.0 . . .	4	6	9	3	2	1	2	2	7	5	6	2		2	5	1	1	3
8.2 . . .	10	6	4	2	9	5	6	8	6	4	2	4	3	1	3	4	1	2
8.4 . . .	9	10	7	9	6	6	8	12	13	10	6	10	6	5	5	4	5	2
8.6 . . .	15	11	10	11	7	6	8	10	11	7	11	8	4	5	10	4	5	7
8.8 . . .	11	6	5	8	7	6	8	7	5	5	1	1	6	4	8	7	3	3
9.0 . . .	3	1	1	5	2	1	5	3		1			2	2	1	4	5	2
9.2 . . .																	1	
Total .	56	49	48	38	36	28	37	46	43	33	30	28	22	19	32	24	21	23

The results are summarised in Table IV and the values of *t* and *P* [Fisher, 1925] are given in Table V.

TABLE IV

Ngasein 2104 *grain lengths of top, middle and bottom portions of panicles*

	(*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	Mean
Top . . .	8·454	8·579	8·557	8·418	8·545	8·600	8·526
Middle . . .	8·267	8·406	8·435	8·307	8·547	8·657	8·436
Bottom . .	8·208	8·414	8·391	8·336	8·502	8·365	8·369

TABLE V

Ngasein 2104, *values of* t *and* P *for differences of means*

Values	Top and middle	Top and bottom	Middle and bottom
t	1·4980	3·4438	1·0252
P	More than 0·1	Less than 0·01	More than 0·2

There is a significant difference in grain lengths between the top and bottom portions. Though the means in other cases do not differ significantly, it appears probable that a relationship exists between position on the panicle and the length of the grains, as the latter decreases towards the base of the panicle.

It has been stated by Ramiah and Parthasarathi [1933] and by van der Stok [1912] that the lower portion of the panicle bears a higher proportion of empty grains and this has been confirmed. The latter also states that the mean grain weight decreases downwards on the panicle and this has also been confirmed as the results given in Table VI show.

TABLE VI

10 × mean weight of grains in grams from different portions of six panicles, Ngasein 2104

	(*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	Mean
Top . . .	2·8006	2·8120	2·7154	2·6862	2·6792	2·7675	2·7434
Middle . . .	2·6507	2·6628	2·6943	2·6286	2·6570	2·7046	2·6663
Bottom . . .	2·5472	2·5738	2·5943	2·5985	2·5790	2·5790	2·5786

The values of *t* and *P* obtained are given in Table VII.

TABLE VII

Values of t *and* P

Values	Top and middle	Top and bottom	Middle and bottom
	2·9050	6·6359	6·3736
P	Between 0·02-0.01	Less than 0·01	Less than 0·01

V. VARIATION BETWEEN PANICLES OF ONE PLANT

Four plants of two local varieties, *Ngasein 2104* and *Theikpan Taungdeikpan* planted at one ft. × one ft. spacing were chosen at random and the panicles were threshed separately, the grains counted and their lengths measured. The number of panicles in each plant, being dependent on the cultural conditions, varies greatly. Means* and variance of means were calculated from individual grains separately for each panicle and for each plant and are given in Tables VIII to XIII.

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* The method of analysis by compartments has been used in this chapter. The calculations of S. E. and variance of means were done separately for individual panicle and individual plants from individual grains.

TABLE

Ngasein 2104, *mean grain lengths of separate panicles, mean variances and standard error*

Penicle No.	Plant No. 1			Plant No. 2			Plant No. 3			Plant No. 4		
	Mean (mm.)	Variance of mean	S. E. of mean of all panicles	Mean (mm.)	Variance of mean	S. E. of mean of all panicles	Mean (mm.)	Variance of mean	S. E. of mean of all panicles	Mean (mm.)	Variance of mean	S. E. of mean of all panicles
a	8·3175	0·001098		8·4955	0·0007401		8·2212	0·0007517		8·5364	0·0005982	
b	8·4726	0·001169		8·4461	0·0005235		8·3000	0·0008724		8·6704	0·0008276	
c	8·4555	0·000695		8·5213	0·0006983		·48 0	0·0011225		8·4487	0·0006044	
d	8·6438	0·001125	0·036945	8·4632	0·0007236	0·030183	8·4943	0·0009467	0·034200	8·6603	0·0007862	0·030120
e	8·5225	0·001087		8·4259	0·0006334		8·4177	0·0008876		8·3978	0·0007624	
f	8·3502	0·000994		8·4392	0·0007212		8·2065	0·0014980		8·5807	0·0008974	
g	8·5382	0·002092		8·3562	0·0007589		8·4600	0·0009494		8·5469	0·0006314	
h				8·5733	0·0009676					8·4852	0·0008937	
i				8·4863	0·0007669					8·6696	0·0012588	
j				8·3062	0·0013340							
k				8·4598	0·0006287							
l				8·5625	9·0011337							
m				8·4865	9·0014024							

TABLE IX

Ngasein 2104, *mean grain lengths of separate plants*

Plant No.	Mean mm.	S. E. of mean	Variance of mean	Remarks
1	8·4375	0·01346	0·0001810	Any panicle mean outside the limits 8·4106 and 8·4644 shows significant aberration.
2	8·4394	0·00790	0·0000624	Any panicle mean outside the limits 8·4236 and 8·4443 shows significant aberration.
3	8·3540	0·01226	0·0001504	Any panicle mean outside the limits 8·3295 and 8·3785 shows significant aberration.
4	8·5384	0·00995	0·0000991	Any panicle mean outside the limits 8·5181 and 8·5579 shows significant aberration.
Total of four plants	8·4424	0·012817		Any plant mean outside the limits 8·4168 and 8·4680 shows significant aberration.

TABLE X

Ngasein 2104, *mean difference and S. E. differences are given in mm.*

Ngasein 2104	Plant No. 2	Plant No. 3	Plant No. 4
Plant No. 1. .	0·0019±0·0015602	0·0835±0·018204	0·1009±0·016736
Plant No. 2. .		0·0854±0·014590	0·0990±0·012710
Plant No. 3. .			0·1844±0·015790

TABLE XI

Theikpan Taungdeikpan, *mean grain lengths of separate panicles, mean variances and standard error*

Panicle No.	Plant No. 1			Plant No. 2			Plant No. 3			Plant No. 4		
	Mean (mm.)	Variance of mean	S. E. of mean of all panicles	Mean (mm.)	Variance of mean	S. E. of mean of all panicles	Mean (mm.)	Variance of mean	S. E. of mean of all panicles	Mean (mm.)	Variance of mean	S. E. of mean of all panicles
a . .	8·647	0·000545	0·03100	8 619	0·000390	0 03170	8·620	0·000577	0·03080	8·605	0·000489	0.03030
b . .	8.577	0·000892		8·550	0·000643		8·776	0·000648		8·522	0·000530	
c . .	8·749	0·001107		8·675	0·000921		8·672	0·000473		8·544	0·000596	
d . .	8·525	0·000699		8·729	0·000874		8·684	0·000559		8·691	0·000595	
e . .	8·781	0·000749		8·622	0·000491		8·692	0·000771		8·736	0·000580	
f . .	8·764	0·000633		8·779	0·000739		8·634	0·000749		8·553	0·000649	
g . .	8·727	0·000608		8·758	0·000835		8·533	0·001608		8·691	0·001312	
h . .	8·543	0·000942		8·674	0·000926		8·697	0·001581		8·609	0·001045	
i . .	8·816	0·000882		8·664	0·000565		8·759	0·000745		8·658	0·000881	
j . .	8·779	0·001124		8·529	0·001043		8·736	0·000570		8·514	0·000693	
k . .	8·774	0·000988		8·583	0·001071		8·645	0·000745		8·503	0·000617	
l . .	8·678	0·000578		8·561	0·001216		8·644	0·001068		8·581	0·001056	
m .	8·566	0·000617		8·563	0·002357		8·729	0·001366		8·680	0·000859	
n . .	8·784	0·001097								8·600	0·001903	
o . .	8·769	0·001988								8·560	0·001037	
p . .										8·543	0·000953	

TABLE XII

Theikpan Taungdeikpan, *mean grain length of separate plants*

Plant No.	Mean (mm).	S. E. of mean	Variance of mean	Remarks
1	8·7010	0·008056	0·0000649	Any panicle mean outside the limits 8·6849 and 8·7171 shows significant aberration.
2	8·6499	0·008013	0·0000642	Any panicle mean outside the limits 8·6339 and 8·6659 shows significant aberration.
3	8·6859	0·007702	0·0000593	Any panicle mean outside the limits 8·6704 and 8·7014 shows significant aberration.
4	8·5976	0·007243	0·0000525	Any panicle mean outside the limits 8·5832 and 8·6120 shows significant aberration.
Total of four plants	8·6586	0·010304		Any plant mean outside the limits 8·6380 and 8·6792 shows significant aberration.

TABLE XIII

Theikpan Taungdeikpan, *mean difference and S. E. differences are given in mm.*

Theikpan Taungdeikpan	Plant No. 2	Plant No. 3	Plant No. 4
Plant No. 1 .	0·05114 ± 0·011363	0·01508 ± 0·011146	0·10337 ± 0·010834
Plant No. 2 .		0·03605 ± 0·011110	0·05224 ± 0·010802
Plant No. 3 .			0·08829 ± 0·010573

From Tables VIII to XIII it appears that in both varieties the lengths of the grains of different panicles of one plant differ from one another significantly. In all cases more than half of the comparisons shown significant results. Between panicles of different plants there are also, as would be expected, significant differences between means. Moreover when each of the panicles is compared with its respective plant mean they show in most cases significant differences and most of the means of the panicles lay outside the limits of their respective plant means.

Comparisons between plants of the same class also show significant differences between the means. This holds good for both varieties and at both one ft. × one ft. and two ft. × two ft. spacings. This is shown in Tables XIV and XV.

Table XIV

Comparison of grain lengths of separate plants of Ngasein 2104 *and* Theikpan Taungdeikpan (*Spacing 2 ft. × 2 ft.*)

Plant No.	Ngasein				Theikpan Taungdeikpan			
	Mean (mm.)	S. E. of mean	Variance of means	S. E. diff. of the mean of 4 plants	Mean	S. E. of mean	Variance of mean	S. E. diff. of the mean of 4 plants
1	8·428	0·005576	0.0000311	0·00748	8·609	0·005323	0·0000283	0·00648
2	8·341	0·006597	0.0000534		8·474	0·005462	0·0000298	
3	8·458	0·006631	0.0000440		8·541	0·006748	0·0000425	
4	8·515	0·006348	0.0000403		8·593	9·005069	0·0000257	

Table XV

Final results showing mean differences and corresponding S. E. differences

Plant No.	Ngasein 2104			Theikpan Taungdeikpan		
	2	3	4	2	3	4
1	0·087±0·00864	0·030±0·00866	0·087±0·00845	0·185±0.00762	0·068±0·00859	0·016±0·00735
2		0·117±0·00935	0·174±0·00915		0·067±0·00868	0·119±0·00745
3			0·057±0·00918			0·052±0·00844

VI. DIFFERENCE IN VARIABILITY BETWEEN DIFFERENT STRAINS SELECTED FROM THE SAME CLASS

Six strains of *Ngasein* (C class) and ten strains of *Kabaing Taungdeikpan* (B class) selected in 1929 from cultivators' varieties and grown for the first time in 1930-31, were chosen for the experiment. From the measurements of length the analyses were done separately and are given in Tables XVI (*a*) and XVI (*b*).

TABLE XVI (*a*)

Variation of grain length of Ngasein (*six strains*)

Strain No.	Degrees of freedom	Sum of squares	Mean square	½ $\log_e$ (mean square)	$\frac{1}{n}$
30—24 . .	499	60·900	0·1220	1·2502	0·002004
30—25 . .	449	62·657	0·1256	1·2643	0·002004
30—26 . .	499	100·350	0·2011	1·4998	0·002004
30—27 . .	499	63·857	0·1280	1·2741	0·002004
30—28 . .	499	50·374	0·1009	1·1558	0·002004
30—31 . .	499	62·990	0·1262	1·2703	0·002004

Standard deviation of z is 0·0447.

TABLE XVI (*b*)

Variation of grain length of Kabaing Taungdeikpan (*ten strains*)

Strain No.	Degrees of freedom	Sum of squares	Mean square	½ $\log_e$ (mean square)	$\frac{1}{n}$
30—104 . .	499	64·950	0·13016	1·2829	0·002004
30—105 . .	499	74·808	0·14992	1·2829	0·002004
30—106 . .	499	68·652	0·13758	1·4003	0·002004
30—107 . .	499	79·176	0·15867	1·3831	0·002004
30—108 . .	499	78·172	0·15666	1·3771	0·002004
30—113 . .	499	67·290	0·13485	1·3007	0·002004
30—119 . .	499	71·366	0·14302	1·3314	0·002004
30—120 . .	499	71·366	0·14302	1·3314	0·002004
30—121 . .	499	75·602	0·15151	1·3594	0·002004
30—123 . .	499	82·092	0·16451	1·4340	0·002004

Standard deviation of z is 0·0447

Ngasein 30-26 is definitely different in variability from other srains, and *Ngasein 30-28* gives a rather high value of z in comparison with the others. Except in one case the value of z fails to pass the required point of significance. In *Taungdeikpan* also the differences in variability are significant in several cases. Therefore variability is not constant even with one type or class. This type of variability is of importance because uniformity of grain size reduces breakage in milling.

VII. DIFFERENCE IN VARIABILITY BETWEEN PURE LINES OF DIFFERENT CLASSES

The sum of squares, mean squares, etc., of four plants each of *Ngasein C2104* and *Theikpan Taungdeikpan* (B class) grown at one ft. × one ft. spacing were calculated separately and are compared in Table XVII.

TABLE XVII

Variation of grain lengths in different classes of pure line paddies

Plant No.		Degrees of freedom	Sum of squares	Mean squares	$\frac{1}{2}$Log$_e$ (mean square)	$\frac{1}{n}$
C2104 Ngasein	1	644	74·236	0·11527	1·2224	0·0015528
	2	1390	120·720	0·08685	1·0807	0·0007194
	3	658	65·308	0·09925	1·1475	0·0015198
	4	767	58·418	0·07616	1·0152	0·0013038
Total	.	3462	337·970	0·09762	1·1392	0·0002889
Theikpan Taungdeikpan.	1	1585	163·210	0·10297	1·1660	0·0006309
	2	1507	146·040	0·09691	1·1355	0·0006636
	3	1817	196·050	0·10790	1·1896	0·0005504
	4	1769	154·330	0·09289	1·1144	0·0005653
Total	.	6681	681·220	0.10196	1·1610	0·0001497

Though the differences in variability between plants are large they cannot be judged significant on these data. The variability does not depend on the type of grain, any two types may or may not differ in variability. In *Ngasein* and *Taungdeikpan* the variability of one plant may differ significantly from the variability of another plant of the same strain, while the two types as a whole do not differ significantly. The results are summarised in Table XVIII. In Table XVIII significant variations are *italicised*.

TABLE XVIII

Differences in variability, Ngasein *and* Taungdeikpan

		Ngasein C 2104			*Taungdeikpan* (B Class)			
		2	3	4	1	2	3	4
Ngasein	1	*0·1484 ±0.0337*	*0·0816±0.0382*	*0·2140±0.0378*	0·0631±0·0320	*0·0836±0·0333*	0·0395±0·0324	*0·1047±0.0333*
	2		*0·0668±0.0334*	*0·0656±0.0318*	*0·0853±0·0259*	*0·0548±0·0263*	*0·1089±0·0252*	0·0337±0·0253
	3			*0·1324±0.0376*	0·0185±0·0328	0·0120±0·0330	0·0421±0·0312	0·0331±0·0313
	4				0·0509±0·0311	0·0204±0·0313	*0·0745±0·0304*	0·0007±0·0306
Taungdeikpan . . .	1					0·0305±0·0255	0·0236±0·0243	*0·0516±0·0244*
	2						*0·0541±0·0246*	0·0211±0·0277
	3							*0·0652±0·0236*

From these data it appears that variability between plants can be held to be significant, but differences in variability between the two classes of paddy are not reliable. Variability may, therefore, agree between quite different classes of paddy and may differ between strains of the same class. Since variation in grain size will affect milling behaviour, it is important that in selection work the degree of variability to which a strain is liable should not be overlooked.

VIII. Effect of spacing on grain size and variability

The effect of spacing on the two varieties, *Ngasein* and *Taungdeikpan*, is shown in Tables XIX, XX, XXI and XXII. The means, variance of mean and standard errors were calculated separately for four plants of each variety at one ft. × one ft. and two ft. × two ft. spacings.

Table XIX

Ngasein, *mean length differences and standard error (2 ft. × 2 ft. spacing and one ft. × one ft. spacing)*

	Plant No.	*Ngasein 2104* 2 ft. × 2 ft.			
		1	2	3	4
Ngasein 1 ft. × 1 ft.	1	0·010±0·0145	*0·097±0·0149*	0·020±0·0150	*0·077±0.0148*
	2	0·011±0·0096	*0·098±0·0102*	0·019±0·0103	*0·076±0.0101*
	3	*0·074±0·0134*	0·013±0·0139	*0·104±0·0140*	*0·159±0.0138*
	4	*0·110±0·0114*	*0·197±0·0119*	*0·080±0·0120*	*0·023±0.0118*

Table XX

Theikpan Taungdeikpan, *mean length differences and S. E. (2 ft. × 2 ft. spacing and 1 ft. × 1 ft. spacing)*

	Plant No.	*Theikpan Taungdeikpan* 2 ft. × 2 ft.			
		1	2	3	4
Theikpan Taungdeikpan 1 ft. × 1 ft.	1	*0·092±0.0097*	*0·227±0·0097*	*0·163±0·0105*	*0·111±0.0095*
	2	*0·041±0.0096*	*0·176±0·0097*	*0·112±0·0104*	*0·060±0.0094*
	3	*0·077±0.0094*	*0·212±0·0094*	*0·145±0·0102*	*0·096±0.0092*
	4	0·011±0.0090	*0·124±0·0091*	*0·060±0·0098*	0·008±0.0088

Mean differences are correct to three places of decimals. Those printed in *italics* are significant.

TABLE XXI

Ngasein *and* Taungdeikpan, *mean lengths, mean variances and standard error for 1 ft. × 1 ft. and 2 ft. × 2 ft. spacings*

Variety	*Ngasein*		*Theikpan Taungdeikpan*	
Spacing	1 ft. × 1 ft.	2 ft. × 2 ft.	1 ft. × 1 ft.	2 ft. × 2 ft.
Mean	8·4424	8·4355	8·6586	8·5542
S. E. of mean	±.005309	±0·00329	±0·004917	±0·002899
Variance of mean	0·00002818	0·00001042	0·00002417	0·00000840
Mean & S. E. difference	0·0069±0·0062		0·1044±0·0057	

Though the difference in grain length is not significant in the case of *Ngasein* the difference in mean length is highly significant in the case of *Theikpan Taungdeikpan*. The effect is in both cases for the grain lengths to decrease with wider spacing, while the number of grains and number of tillers per plant increases.

The effect on the degree of variablity is shown in Table XXII.

TABLE XXII

Ngasein *and* Theikpan Taungdeikpan, *differences in variability at 1 ft. × 1 ft. and 2 ft. × 2 ft. spacings*

Variety	Degrees of freedom	Sum of squares	Mean squares	½ $\log_e$ (mean square)	$\frac{1}{n}$
Ngasein 1 ft. × 1 ft.	3462	337·97	0.09762	1·1392	0·0002889
Ngasein 2ft. × 2 ft.	7991	635·92	0.07958	1·0371	0·0001251
Theikpan Taungdeikpan 1 ft. × 1 ft.	6681	681·22	0.10196	1·1610	0.0001497
Theikpan Taungdeikpan 2 ft. × 2 ft.	14451	1756·70	0.12156	1·2490	0·0000692

For *Ngasein* ½ log difference is 0·1021 and S. D. of z=0·01438

For *Taungdeikpan* ½ $\log_e$ difference is 0·0880 and S. D. of z=0·01045.

In both varieties the differences in variability are significant even within one variety, indicating that variability is easily affected by changes in spacing.

IX. EFFECT OF HARVESTING DATE ON GRAIN SIZE

There being no sharp indication of when paddy has reached a degree of ripeness most sutable for harvesting, there is in practice a great deal of uncertainty. It has been the practice in this laboratory to estimate life-period as the number of days from sowing to flowering *plus* thirty days, but this arbitrary period of thirty days for the grain filling and ripening period after flowering is in many cases too short. It holds for short-lived varieties of 150 days life-period or less, but is not correct for long-lived types. Further paddies of the same life-period often require different lengths of time from flowering to harvest. The exact stage at which paddy is reaped is held, with good reason, to affect its milling and quality, and the optimum stage is not the same for all. For instance, *Taungdeikpan* is usually reaped while distinctly unripe, whereas *Ngasein* is allowed to stand until dead ripe.

In 1931-32 *Ngasein 2104* was harvested at different dates after flowering and measurements of length and breadth were made. The figures are shown in Tables XXIII and XXIV.

TABLE XXIII

Ngasein 2104, *length of grain in mm. after harvesting on different dates*

Harvesting dates	32 days after flowering 11th Dec. 1931	36 days after flowering 15th Dec. 1931	40 days after flowering 19th Dec. 1931	44 days after flowering 23rd Dec. 1931	48 days after flowering 27th Dec. 1931
Standard deviation . .	0·28448	0·26418	0·28272	0·33564	0·31992
Mean	8·6004	8·6132	8·5588	8·5300	8·5368
S. E. of S. D. . . .	0·008996	0·008354	0·008941	0·010614	0·010116
S. E. of mean . . .	0·012722	0·011817	0·012643	0·015010	0·014307

TABLE XXIV

Ngasein 2104, *breadth of grain in mm. after harvesting on different dates*

Harvesting dates	11th Dec. 1931	15th Dec. 1931	19th Dec. 1931	23rd Dec. 1931	27th Dec. 1931
Standard deviation . .	0·11098	0·12590	0·11826	0·13169	0·12236
Mean	3·4532	3·4160	3·4010	3·3908	3·4132
S. E. of S. D. . . .	0·003509	0·003981	0·003740	0·004164	0·003869
S. E. of mean . . .	0·004961	0·005631	0·005289	0·005889	0·005472

TABLE XXV

Ngasein 2104, *mean differences and S. E. for length of grain when harvested on different dates*

Harvesting dates	15th Dec. 1931	19th Dec. 1931	23rd Dec. 1931	27th Dec. 1931
11th Dec. 1931	0·0128±0·017362	*0·0460±0·017936*	*0·0704±0·019677*	*0·0636±0·019145*
15th Dec. 1931		*0·0544±0·017305*	*0·0832±0·019100*	*0·0764±0·018555*
19th Dec. 1931			0·0288±0·019625	0·0220±0·019094
23rd Dec. 1931				0·0068±0·020736

Those printed in *italics* are significant.

Table XXVI

Ngasein 2104, *mean differences and S. E. for breadth of grain when harvested on different dates*

Harvesting dates	15th Dec. 1931	19th Dec. 1931	23rd Dec. 1931	27th Dec. 1931
11th Dec. 1931	*0·0372±0·007503*	*0·0522±0·007246*	*0·0624±0·007701*	*0·0400±0·00738*
15th Dec. 1931		0·0150±0.007720	*0·0252±0·008149*	0·0028±0·007849
19th Dec. 1931			0·0102±0·007912	0·0122±0·007603
23rd Dec. 1931				*0·0224±0·008037*

Those printed in *italics* are significant.

The measurements were done several months after harvest when the samples had reached the same stage of air-dryness. From the tables it will be seen that both dimensions have varied significantly in most cases. The tendency is for later harvesting to produce shorter and narrower grains.

When the effect of harvesting date on the degree of variability was measured, though some significant differences occurred, no general tendency could be discovered and it seems probable that the variations were due to chance.

X. Effect of season on grain weights

The data were obtained from the Permanent Manurial Experiment on the Mandalay Agricultural College Farm. The details of the lay-out have been reported in the Annual Reports of the Agricultural College Farm, Mandalay, from 1927 onwards. Briefly there are seventy-four plots of 0·1 acre of which thirty-eight are untreated. Each treatment has been repeated four times and there is an un-treated plot between each pair of treated plots. The variety is *Ngasein 2104.* The treatments are :—

(*a*) Lime, 5 cwt. calcium oxide per acre every four years. Second application in 1930.

(*b*) Sodium nitrate, 40 lbs. nigtrogen per acre.

(*c*) Ammonium sulphate, 40 lbs. nitrogen per acre.

(*d*) Superphosphate, 40 lbs. phosphoric acid per acre.

(*e*) Bone-meal, 40 lbs. phosphoric acid per acre.

(*f*) Potassium sulphate, 40 lbs. potassium oxide per acre.

(*g*) Ammonium sulphate, 40 lbs. nitrogen per acre ; superphosphate, 40 lbs. phosphoric acid per acre.

(*h*) Ammonium sulphate, 40 lbs. nitrogen ; superphosphate, 40 lbs. phosphoric acid ; potassium sulphate, 40 lbs. potassium oxide per acre.

(*i*) Farmyard manure, 40 lbs. nitrogen per acre.

Manures are applied shortly before transplanting. The bone-meal used has been a very coarse grade hitherto.

Weights of hundred grains from each plot were taken in the seasons 1929-30, 1930-31 and 1931-32. All the thirty-eight controls were not treated separately but instead eighteen means were used, these being arrived at for each year by first taking the means of two adjacent controls lying on opposite sides of treated plots and then taking means of the two adjacent means of controls of the two rows, the experiment being laid out in two blocks of two replications each with an irrigation distributory running between.

TABLE XXVII

Permanent Manurial Series (weight of 100 grains of paddy of pooled means of controls)

Serial No.	1929-30	1930-31	1931-32	Total
1	2·947	2·865	2·945	8·757
2	2·994	2·928	2·925	8·847
3	2·921	2·953	2·936	8·810
4	2·924	2·920	2·959	8·803
5	2·965	2·930	2·956	8·851
6	2·943	2·903	2·962	8·808
7	2·911	2·883	2·977	8·771
8	2·918	2·933	2·980	8·831
9	2·943	2·910	2·978	8·831
10	2·948	2·900	2·960	8·808
11	2·928	2·937	2·928	8·793
12	2·948	2·923	2·990	8·861
13	2·890	2·870	2·990	8·750
14	2·932	2·840	2·960	8·732
15	2·916	2·868	2·974	8·758
16	2·857	2·863	2·987	8·707
17	2·878	2·880	3·008	8·766
18	2·911	2·907	3·016	8·834
Total .	52·674	52·213	53·431	158·318

TABLE XXVIII

Analysis of variance

Due to	Degrees of freedom	Sum of squares	Mean squares	½ Log$_e$ (mean square)	Remarks
Years	2	0·0421	0·021050	3·7390	Significant
Replications . . .	17	0·0110	0·000647	2·0850	
Residual . . .	34	0·0330	0·000970	2·1844	
Total .	53	0·0861	One per cent point is 0·8423		

The analysis of variance shows that seasonal effect on the weight is significant. The S. E. for the total of eighteen means being 0·132 the difference between any two years is significant. Of the three years, 1931-32 has given the heaviest grains and 1930-31 the lightest.

XI. EFFECT OF SEASON ON GRAIN LENGTH

Figures for the seasonal variation in grain length are available only for *Theikpan Taungdeikpan* for the years 1930, 1931 and 1933. The grains were taken from increase plots planted two ft. × one ft. and receiving the same treatments. The figures are shown in Tables XXIX and XXX.

TABLE XXIX

Theikpan Taungdeikpan, *seasonal variation in grain length (mm.)*

Year	1930-31	1931-32	1933-34
Mean	8·6008	8·7180	8·7530
S. E. of mean . . .	0·018090	±0·017039	±0·022175

TABLE XXX

Theikpan Taungdeikpan, *mean length differences and S. E. of differences*

Year	Means (mm.)	Difference from	
		1931-32	1933-34
1930-31 . . .	8·6008	*0·1172 ± 0·0227*	*0·1522 ± 0·0286*
1931-32 . . .	8·7180		0·0350 ± 0·0280

Those printed in *italics* are significant.

The difference between the means of 1933 and 1931 are not reliable, but in 1931 the length was definitely greater than in 1930, and also 1933 is significantly longer than in 1930. This agrees with the data for *Ngasein* grain weights.

Differences in degree of variability from year to year in grain lengths were not found to be significant and only in one case did variability in grain lengths show a reliable difference.

XII. EFFECT OF MANURE ON GRAIN WEIGHT

(a) *Paddy*

The weights of one hundred grains were taken from each plot of the Permanent Manurial Series. The means of each pair of controls on opposite sides of treated plots were used for comparisons. The figures relate to the years 1929-30, 1930-31 and 1931-32.

TABLE XXXI

Effect of manure on weight of paddy grains (grms.)

Treatment	Year	Mean weight (100 grains)		Percentage increase or decrease	Fisher's *t*
		Treated	Control		
Lime	1929-30	2·9655	2·9476	+0·6073	0·8476
	1930-31	2·8650	2·8825	—0·6071	0·1225
	1931-32	2·9823	2·9474	+1·1841	1·6530

TABLE XXXI—(*contd*)

Treatment	Year	Mean weight (100 grains)		Percentage increase or decrease	Fisher's *t*
		Treated	Control		
Sodium nitrate . . .	1929-30	2·9327	2·9610	—0·9558	0·9034
	1930-31	2·9125	2·9325	—0·6820	0·5123
	1931-32	2·9866	2·9484	+1·2956	1·9060
Ammonium sulphate . .	1929-30	2·9490	2·9341	+0·5078	0·4327
	1930-31	3·0075	2·9375	+2·3885	1·6847
	1931-32	3·0032	2·9632	+1·3499	2·1760
Superphosphate . .	1929-30	2·9402	2·9065	+1·1594	0·9908
	1930-31	2·9275	2·8950	+1·1226	1·2460
	1931-32	3·0022	2·9746	+0·9279	1·0034
Bone-meal . . .	1929-30	2·9527	2·9481	+0·1560	0·2046
	1930-31	2·9575	2·8850	+2·5130	1·8785
	1931-32	2·9811	2·9580	+0·7809	1·5860
Potassium sulphate . .	1929-30	2·9352	2·9297	+0·1877	0·2091
	1930-31	2·9025	2·8850	+0·4842	0·7285
	1931-32	2·9795	2·9677	+0·3968	0·3588
Ammonium sulphate + superphosphate	1929-30	2·9985	2·8842	+3·9630	*3·1640*
	1930-31	2·9600	2·8775	+2·8671	*5·1120*
	1931-32	3·0469	2·9869	+2·0087	2·2240
Ammonium sulphate + superphosphate + potassium sulphate	1929-30	3·0337	2·8975	+4·7006	*5·0160*
	1930-31	2·990	2·9062	+2·8835	2·1050
	1931-32	3·0486	2·9942	+1·8168	*3·2080*
Farmyard manure . .	1929-30	3·0162	2·9286	+3·0547	*2·6120*
	1930-31	2·9325	2·9087	+1·1621	0·6163
	1931-32	3·0376	2·9976	+1·3344	1·5770

Five per cent value of *t* is 2·4470.

In no case have dressings of single fertilizers given significant results. Ammonium sulphate in combination with superphosphate has given significant increases of mean grain weight in 1929-30 and 1930-31 but just fails to show a reliable increase in 1931-32, although the actual weight in the third year was the highest. In that year the mean weight of the adjacent controls was also unusually high. It is considered that there is little doubt that this combination of fertilizers causes a true increase in mean grain weight.

In the case of ammonium sulphate + superphosphate + potassium sulphate the increases are significant in 1929-30 and 1931-32. In 1930-31 inspite of an increase of 2·88 per cent the result is not reliable. There has been a decrease in the percentage increase in each suceeding year. This may be due to depletion of some nutrient other than those added in these fertilizers on account of the heavy yields of grain and straw from these plots.

Farmyard manure has given a significant increase only in the first year and it seems doubtful whether this manure has any definite effect on grain weight.

(b) *Effect of manures on weight of husked rice*

Husked rice (not polished) from the Permanent Manurial Series was compared in the same way as the paddy and the results are shown in Table XXXII.

TABLE XXXII

Effect of manure on weight of husked rice (Ngasein 2104)

Treatment	Year	Mean weight in grms. (100 grains)		Percentage increase or decrease	Fisher's *t*
		Treated	Control		
Lime	1929-30	2·2805	2·2774	+0·0136	0·1873
	1930-31	2·2750	2·2750	0	0
	1931-32	2·3683	2·3625	+0·2455	0·4544
Sodium nitrate . .	1929-30	2·2570	2·2724	—0·6777	1·1284
	1930-31	2·3050	2·3050	0	0
	1931-32	2·3549	2·3500	+0·2085	0·2896

TABLE XXXII-(*contd*)

Treatment	Year	Mean weight in gram (100 grains)		Percentage increase or decrease	Fisher's *t*
		Treated	Control		
Ammonium sulphate .	1929-30	2·2930	2·2691	+1·0533	1·6250
	1930-31	2·3600	2·3137	+2·0012	*3·2460*
	1931-32	2·3934	2·3502	+1·8381	2·0820
Superphosphate . .	1929-30	2·2962	2·2596	+1·6198	*2·9241*
	1930-31	2·3350	2·2937	+1·8006	1·9640
	1931-32	2·4045	2·3679	+1·5453	1·8630
Bone-meal . . .	1929-30	2·2732	2·2675	+0·2514	0·2940
	1930-31	2·3100	2·3087	+0·0563	0·5308
	1931-32	2·3610	2·3679	—0·2914	0·4526
Potassium sulphate . .	1929-30	2·2687	2·2655	+0·1413	0·1645
	1930-31	2·2850	2·2775	+0·3293	0·4789
	1931-32	2·3438	2·3538	—0·4248	0·9755
Ammonium sulphate+superphosphate	1929-30	2·3107	2·2537	+2·5292	*2·6960*
	1930-31	2·3450	2·2875	+2·5143	*2·7565*
	1931-32	2·4297	2·3778	+2·1827	*2·4705*
Ammonium sulphate+superphosphate+potassium sulphate	1929-30	2·3725	2·2622	+4·8759	*5·6313*
	1930-31	2·3627	2·3050	+2·7115	2·3635
	1931-32	2·4106	2·3870	+0·9886	1·6890
Farmyard manure . .	1929-30	2·3282	2·2789	+2·1634	1·5528
	1930-31	2·3150	2·3812	+1·2020	1·0963
	1931-32	2·4206	2·3828	+1·5864	*3·7490*

Five per cent value of *t* is 2·4470.

Lime, sodium nitrate, bone-meal and superphosphate appear to be definitely without effect. Although ammonium sulphate and superphosphate fail to show significant responses, the increases are of a size to suggest a real effect. Ammonium sulphate and superphosphate together give a definite increase in weight in every year but when potassium sulphate is added the increase is significant only in one year. Farmyard manure gives a significant increase in only one year.

(c) *Effect of manures on the weight of polished rice*

The weighings, etc., for polished rice from the Permanent Manurial Experiment are given in Table XXXIII.

TABLE XXXIII

The effect of manure on weight of polished rice (Ngasein 2104)

Treatments	Year	Mean weight in grms. (10 grains)		Percentage increase or decrease	Fisher's *t*
		Treated	Control		
Lime	1929-30	2·144	2·127	+0·0799	1·060
	1930-31	2·127	2·127	0	0
Sodium nitrate . . .	1929-30	2·087	2·122	—1·6994	2·000
	1930-31	2·150	2·154	—0·1773	0·397
Ammonium sulphate . .	1929-30	2·164	2·122	+1·9792	*4·950*
	1930-31	2·210	2·156	+2·5046	*4·972*
Superphosphate. . .	1929-30	2·140	2·109	+1·4698	1·750
	1930-31	2·170	2·129	+1·9258	2·345
Bone-meal . . .	1929-30	2·156	2·112	+2·0834	1·373
	1930-31	2·155	2·144	+0·5131	0·352
Potassium sulphate . .	1929-30	2·122	2·116	+0·2835	0·3661
	1930-31	2·145	2·145	0	0
Ammonium sulphate + superphosphate	1929-30	2·164	2·116	+2·2684	*3·100*
	1930-31	2·207	2·144	+2·9385	*4·338*
Ammonium sulphate + superphosphate + potassium sulphate	1929-30	2·197	2·126	+3·3396	*2·636*
	1930-31	2·212	2·162	+2·3127	*2·811*
Farmyard manure . .	1929-30	2·175	2·133	+1·9690	1·430
	1930-31	2·150	2·137	+0·6083	0·552

Five per cent value of *t* is 2·4470

Lime, superphosphate, bone-meal and potassium sulphate increased the polished rice weights but the effect is not definite, while sodium nitrate decreased the weight though the effect was negligible. Ammonium sulphate alone and in combination produced definite effects on the polished rice weight. The effect of combined manures seemed to be additive. Farmyard manure failed to show a significant response in both years.

For comparison between one treatment and another and between years, the following modified method of calculation was done for analysis of variance.*

The weights of one hundred grains for three years each of seventy four plots were obtained. Means of the controls on either side of the treated were then worked out, so that nine means for controls for each replication of each treatment were obtained. Means of nine means were then calculated for four replications. Hence there remained four controls and thirty-six manured giving a total of forty figures for each year, *i.e.*, ten treatments of four replications. The weighings are tabulated in Table XXXIV.

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* Though the " analysis of variance " method is not strictly applicable to the present case, an effort has been made in these tables to separate the several items by the above method.

TABLE XXXIV

Weight of paddy in grms.

Treatments	Lime	Sodium-nitrate	Am. sulphate	Super phosphate	Bone-meal	Potassium sulphate	Am. sulphate +super	Am. sulphate + super + potassium sulphate	F. Y. M.	Control	Total
1929-30 . . .	2·960	2·903	2·900	2·932	2·972	2·963	2·953	3·035	2·990	2·947	29·455
	2·942	2·908	2·958	2·873	2·917	2·975	2·982	3·000	2·950	2·870	29·375
	2·963	2·950	2·980	2·978	3·000	2·948	3·022	3·060	3·030	2·826	29·757
	2·997	2·970	2·958	2·978	2·922	2·955	3·037	3·040	3·095	2·949	29·901
Total .	11·862	11·731	11·796	11·761	11·811	11·741	11·994	12·135	12·065	11·592	118·488
Mean	2·965	2·933	2·949	2·940	2·953	2·935	2·998	3·034	3·016	2·898	
1930-31 . . .	2·860	2·850	2·940	2·950	3·020	2·900	2·970	3·010	2·930	2·919	29·319
	2·950	2·910	2·970	2·900	2·900	2·850	2·980	2·950	2·840	2·867	29·117
	2·750	2·850	3·000	2·910	2·990	2·940	2·950	3·050	2·980	2·980	29·330
	2·900	3·040	3·120	2·950	2·920	2·920	2·940	2·950	2·990	2·908	29·638
Total .	11·460	11·650	12·030	11·710	11·830	11·610	11·840	11·960	11·740	11·604	117·434
Mean	2·865	2·912	3·007	2·927	2·958	2·902	2·960	2·990	2·935	2·901	
1931-32 . . .	2·995	2·968	3·000	2·929	3·001	2·901	3·019	3·019	3·059	2·948	29·839
	3·021	2·978	2·994	3·004	2·978	3·002	2·998	3·045	3·020	2·967	30·007
	2·926	2·969	3·008	3·033	2·983	2·978	3·087	3·063	2·987	2·945	29·979
	2·987	3·031	3·011	3·042	2·963	3·037	3·084	3·067	3·084	3·003	30·309
Total .	11·929	11·946	12·013	12·008	11·925	11·918	12·188	12·194	12·154	11·863	120·134
Mean	2·982	2·986	3·003	3·002	2·981	2·979	3·047	3·048	3·036	2·965	
Grand Total .	35·251	35·327	35·839	35·479	35·566	35·269	36·022	36·289	35·955	35·059	356·056

Analysis of variance for the year 1929-30 is given in Table XXXV.

TABLE XXXV

Analysis of variance (1929-30)

Due to	Degrees of freedom	Sum of squares	Mean square	$\frac{1}{2}$ Log$_e$ (mean square)
Replication	3	0·018496	0·006165	4·3520
Treatments	9	0·063245	0·007027	4·4288
Residual	27	0·038191	0·001414	3·6270
Total .	39	0·119932		

One per cent value of z is 0·7631

5 per cent value of z is 0·5427

S. E. of mean of treatments is 0·0188

Though it does not quite agree with the result obtained by the method of paired differences in comparing with the control, yet in most cases the results agree with the general expectation. Effective manures give significant differences over controls.

TABLE XXXVI

Final results for 1929-30 (weight of paddy)

Treatments	Mean weights	Difference from								
		1	2	3	4	5	6	7	8	9
Control	2·898									
Lime	2·965	*+0·067*								
Sodium nitrate	2·933	+0·035	—0·032							
Ammonium sulphate	2·949	*+0·051*	—0·016	+0·016						
Superphosphate	2·940	*+0·042*	—0·025	+0·007	—0·009					
Bone-meal	2·953	*+0·055*	—0·012	+0·020	+0·004	+0·013				
Potassium sulphate	2·935	+0·037	—0·030	+0·002	—0·014	—0·005	—0·018			
Am. sulph.+super	2·998	*+0·100*	+0·033	*+0·065*	*+0·049*	*+0·058*	*+0·045*	*+0·063*		
Am. sulph+super.+pot.	3·034	*+0·136*	*+0·069*	*+0·101*	*+0·088*	*+0·094*	*+0·081*	*+0·099*	+0·036	
Farmyard manure	3·016	*+0·118*	*+0·059*	*+0·083*	*+0·067*	*+0·076*	*+0·063*	*+0·081*	+0·018	—0·018

For five per cent point the difference must exceed 0·038577

It is clear from the above that increase in weight is considerable and significant in cases of effective manures such as ammonium sulphate and superphosphate. Potassium sulphate increases the weight but not significantly. The effect of combined manures appears to be roughly additive.

Increase due to ammonium sulphate alone . . . =0·051
Increase due to superphosphate alone . . . =0·042
Sum . =0·093

Increase due to ammonium sulphate and superphosphate together . . . . =0·100
Difference . =0·007

The analysis of variance for the year 1930-31 is given in Table XXXVII.

TABLE XXXVII

Analysis of variance for 1930-31 (weight of paddy)

Due to	Degrees of freedom	Sum of squares	Mean square	½ Loge (mean square)
Replications . . .	3	0·013734	0·004578	4·2146
Treatments	9	0·068320	0·007591	4·4674
Residual	27	0·130851	0·004846	4·2430
Total .	39	0·212905	z-test fails	

S. E. of the mean of treatments=0.034799.

TABLE XXXVIII

Final results for 1930-31 (weight of paddy)

Treatments	Mean weight	Difference from treatment								
		1	2	3	4	5	6	7	8	9
Control	2·901									
Lime	2·865	—0·036								
Sodium nitrate	2·912	+0·011	+0·047							
Ammonium sulphate	3·007	+0·106	*+0·142*	*+0·095*						
Superphosphate	2·927	+0·026	+0·062	+0·015	*—0·080*					
Bone-meal	2·958	+0·057	*+0·093*	+0·046	—0·049	+0·031				
Potassium sulphate	2·902	+0·001	+0·037	—0·010	*—0·105*	—0·025	—0·056			
Am. sulph. + super.	2·960	+0·059	*+0·095*	+0·048	—0·047	+0·033	+0·002	+0·058		
Am. sulph. + super. + pot.	2·990	*+0·089*	*+0·125*	*+0·078*	—0·017	+0·063	+0·032	*+0·088*	+0·030	
Farmyard manure	2·935	+0·034	+0.070	+0·023	*—0·072*	+0·008	—0·023	+0·033	—0·025	—0·055

For five per cent point the difference must exceed 0.07148

In the year 1930-31 ammonium sulphate alone gave the largest increase while lime had a negative effect though not significant.

The analysis of variance for the year 1931-32 is given in Table XXXIX.

TABLE XXXIX

Analysis of variance for 1931-32 (weight of paddy)

Due to	Degrees of freedom	Sum of squares	Mean square	$\frac{1}{2}$ Log$_e$ (mean square)
Replications . . .	3	0·010740	0·003580	4·0917
Treatments	9	0·033748	0·003749	4·1147
Residual	27	0·029507	0·001093	3·4982
Total .	39	0·073995	z-test passes 5 per cent point	

S. E. of mean of treatments is 0·0165287

TABLE XL

Final result for 1931-32 (weight of paddy)

Treatments	Mean weights	Difference from treatment								
		1	2	3	4	5	6	7	8	9
Control	2·965									
Lime	2·982	+0·017								
Sodium nitrate	2·986	+0·021	+0·004							
Ammonium sulphate	3·003	+0·038	+0·021	+0·017						
Superphosphate	3·002	+0·037	+0·020	+0·016	—0·001					
Bone-meal	2·981	+0·016	—0·001	—0·005	—0·022	—0·021				
Potassium sulphate	2·979	+0·014	—0·003	—0·007	—0·024	—0·023	—0·002			
Amm. sulph.+super.	3·047	+0.082	+0·065	+0·061	+0·044	+0·045	+0·066	+0·068		
Amm. sulph.+super.+pot.	3·048	+0·083	+0·066	+0·062	+0·045	+0·046	+0·067	+0·069	+0·001	
Farmyard manure	3·037	+0·072	+0·055	+0·051	+0·034	+0·035	+0·056	+0·058	—0·010	—0·011

For five per cent point the difference must exceed 0·03395

The final results of 1931-32 agree closely with the results of 1929-30. Effective manures have a definite effect on the weights. Ammonium sulphate, superphosphate and potassium sulphate were additive in effect. Farmyard manure seems to have about the same effect as the combined effect of the three manures.

Figures for the three years were combined and statistical analysis was done by the method of analysis of variance into parts.

The analysis is given in Table XLI, and the final result for comparison is given in Table XLII.

TABLE XLI

Analysis of variance. Weight of paddy (three years combined)

Due to	Degrees of freedom	Sum of squares	Mean square	$\frac{1}{2}$ Log$_e$ (mean square)	Value of z
Years . . .	2	0·072593	0·036296	5·2496	1·7266
Replication . . 3 Interaction between year and replication . 6	9	0·062971			
Treatment . . .	9	0·251675	0·279640	5·1192	1·5962
Residual . . .	99	0·113184	0·001143	3·5230	
Total .	119	0·500423			

One per cent value of z for years is 0·7636

One per cent value of z for treatments is 0·4604

S. E. of mean of four plots (treatments) is 0·01868

S. E. of total of twelve plots is 0·1290

S. E. of total of forty plots is 0·2363

S. E. of total of ten plots is 0·1180

Grain weight was highest in 1931-32 and lowest in 1930-31. The differences must be judged significant.

Final result for comparison between the treatments in different years and between treatment totals for three years is given in Table XLII.

TABLE XLII

Final results

Mean of four plots	Control	Lime	Sodium nitrate	Ammonium sulphate	Super-phosphate	Bone-meal	Pot. sulphate	Am. sulph. +super.	Am. sulph. +sulper +pot. sulph.	F. Y. M.	S. E.
1929-30	2·898	2·965	2·933	2·949	2·940	2·953	2·935	2·998	3·034	3·016	0·01868
1930-31	2·901	2·865	2·917	3·007	2·927	2·958	2·902	2·960	2·990	2·935	
1931-32	2·965	2·982	2·986	3·003	3·002	2·981	2·979	3·047	3·048	3·037	
Total of three years (total of 12 plots)	35·059	35·251	35·327	35·839	35·479	35·566	35·269	36·022	26·289	35·955	0·12900

Of the manures tested ammonium sulphate and its combinations gave the heaviest grain. Superphosphate and Farmyard manure, the latter containing the combination of the three effective manures, gave considerable increases. Lime and potassium sulphate on the whole were not effective, while sodium nitrate and bone-meal gave effective response to a considerable extent. Ammonium sulphate and its combinations show significant increases over other manures such as lime, sodium nitrate and potassium sulphate.

The weighings of husked rice are given in Table XLIII.

TABLE XLIII

Weights of husked rice

Treatments	Control	Lime	Sodium nitrate	Ammonium sulphate	Superphosphate	Boue-meal	Pot. sulph.	Am. sulph. +super	Am. sulph. +super +pot. sulph.	F. Y. M.	Total
1929-30	2·275	2·288	2·253	2·283	2·300	2·282	2·257	2·343	2·333	2·283	22·897
	2·242	2·238	2·240	2·277	2·305	2·248	2·230	2·275	2·363	2·300	22·718
	2·279	2·293	2·250	2·322	2·300	2·310	2·283	2·335	2·397	2·310	23·079
	2·272	2·303	2·285	2·290	2·280	2·253	2·305	2·290	2·397	2·420	23·095
Total .	9·068	9·122	9·028	9·172	9·185	9·093	9·075	9·243	9·490	9·313	91·789
Mean	2·267	2·280	2·257	2·293	2·296	2·273	2·269	2·311	2·372	2·328	
1930-31	2·299	2·280	2·260	2·340	2·330	2·330	2·280	2·350	2·360	2·290	23·119
	2·273	2·290	2·320	2·340	2·310	2·320	2·270	2·340	2·340	2·260	23·063
	2·299	2·220	2·300	2·370	2·310	2·330	2·300	2·380	2·380	2·370	23·259
	2·302	2·310	2·340	2·390	2·390	2·260	2·290	2·310	2·390	2·340	23·322
Total .	9·173	9·100	9·220	9·440	9·340	9·240	9·140	9·380	9·470	9·260	92·763
Mean	2·293	2·275	2·305	2·360	2·335	2·310	2·285	2·345	2·367	2·315	
1931-32	2·351	2·351	2·381	2·385	2·367	2·381	2·305	2·415	2·407	2·412	23·755
	2·377	2·383	2·303	2·410	2·383	2·337	2·361	2·390	2·394	2·403	23·741
	2·365	2·359	2·355	2·394	2·425	2·334	2·355	2·447	2·413	2·436	23·883
	2·376	2·381	2·381	2·385	2·443	2·392	2·356	2·467	2·429	2·432	24·042
Total .	9·469	9·474	9·420	9·574	9·618	9·444	9·377	9·719	9·643	9·683	95·421
Mean	2·367	2·368	2·355	2·393	2·404	2·361	2·344	2·430	2·411	2·421	
Grand total .	27·710	27·696	27·668	28·186	28·143	27·777	27·592	28·342	28·603	28·256	279·973

The analysis of variance is given in Table XLIV and final results for comparison in Table XLV.

TABLE XLIV

Analysis of variance (Weight of husked rice, 1929-30)

Due to	Degrees of freedom	Sum of squares	Mean square	$\frac{1}{2}$ Log_e
Replications	3	0·009427	0·003142	
Treatments	9	0·018860	0·002095	3·8238
Residual	27	0·045085	0·001669	3·7100
Total .	39	0·073372	z-test fails	

S. E. of mean of treatments is 0·0204

TABLE XLV

Final result (1929-30) (weight of husked rice)

Treatments	Mean weights	Difference from treatment								
		1	2	3	4	5	6	7	8	9
1. Control	2·267									
2. Lime	2·280	+0·013								
3. Sodium nitrate	2·257	—0·010	—0·023							
4. Ammonium sulphate	2·293	+0·026	+0·013	+0·036						
5. Superphosphate	2·296	+0·029	+0·016	+0·039	+0·003					
6. Bone-meal	2·273	+0·006	—0·007	+0·016	—0·020	—0·023				
7. Potassium sulphate	2·269	+0·002	—0·011	+0·012	—0·024	—0·027	—0·004			
8. Amm. sulph. +super.	2·311	*+0·044*	+0·031	*+0·054*	+0·018	+0·015	+0·038	*+0·042*		
9. Amm. sulph. +super +pot.	2·372	*+0·105*	*+0·092*	*+0·115*	*+0·079*	*+0·076*	*+0·099*	*+0·103*	*+0·061*	
10. Farmyard manure	2·328	*+0·061*	*+0·048*	*+0·071*	+0·035	+0·032	*+0·055*	*+0·059*	+0·017	*—0·044*

For five per cent point the difference must exceed 0·0418608

Over the control the eighth, ninth and tenth treatments gave significant increases. Ammonium sulphate, superphosphate and potassium sulphate did not produce a substantial effect separately, but in combination a considerable response was obtained. Farmyard manure gave the second largest increase on the weight of husked rice. Sodium nitrate alone decreased the weight of husked rice.

The analysis of variance for the year 1930-31 is given in Table XLVI, and the final result is given in Table XLVII.

TABLE XLVI

Analysis of variance, 1930-31 (weight of husked rice)

Due to	Degrees of freedom	Sum of squares	Mean square	$\frac{1}{2}$ Log$_e$
Replications . . .	3	0·004335	0·001445	
Treatment	9	0·036053	0·004006	4·1479
Residual	27	0·025493	0·000944	3·4250
Total .	39	0·065881	z-test passes one per cent point	

S. E. of mean of treatments is 0·0154

TABLE XLVII

Final result for 1930-31 (weight of husked rice)

Treatments	Mean weight	Difference from treatment								
		1	2	3	4	5	6	7	8	9
1. Control	2·293									
2. Lime.	2·275	—0·018								
3. Sodium nitrate	2·305	+0·012	+0·030							
4. Ammonium sulphate	2·360	+0·067	+0·085	+0·055						
5. Superphosphate	2·335	+0·042	+0·060	+0·030	—0·025					
6. Bone-meal	2·310	+0·017	+0·035	+0·005	—0·050	—0·025				
7. Potassium sulphate	2·295	—0·008	+0·010	—0·020	—0·075	—0·050	—0·025			
8. Amm. sulph. + super . . .	2·345	+0·052	+0·070	+0·040	—0·015	+0·010	+0·035	+0·060		
9. Amm. sulph. + super + pot. sulph .	2·367	+0·074	+0·092	+0·062	+0·007	+0·032	+0·057	+0·082	+0·022	
10. Farmyard manure . . .	2·315	+0·022	+0·040	+0·010	—0·045	--0·020	+0·005	+0·030	—0·030	– 0·052

For five per cent point the difference must exceed 0·0316008

The value of z being significant, the result given above is reliable, while the result given in Table XLV, though taken into consideration, is not reliable.

From these results it is seen that, lime and potassium sulphate reduced the mean weight but not significantly, while ammonium sulphate, superphosphate and their combinations show a definite increase.

Analysis for the year 1931-32 is given in Table XLVIII, and the final result in Table XLIX.

TABLE XLVIII

Analysis of variance, 1931-32 (weight of husked rice)

Due to	Degrees of freedom	Sum of squares	Mean square	$\frac{1}{2}$ Log_e
Replications . . .	3	0·005875	0·001985	
Treatments	9	0·032469	0·003607	4·0953
Residual . . .	27	0·055273	0·002047	3·8121
Total .	39	0·093617	z-test fails	

S. E. of mean of treatment is 0·0226

TABLE XLIX

Final results for 1931-32 (weight of husked rice)

Treatment	Mean weight	Difference from treatment								
		1	2	3	4	5	6	7	8	9
1. Control	2·367									
2. Lime	2·368	+0·001								
3. Sodium nitrate	2·355	—0·012	—0·013							
4. Ammonium sulphate . . .	2·393	+0·026	+0·025	+0·038						
5. Superphosphate	2·404	+0·037	+0·036	*+0·049*	+0·011					
6. Bone-meal	2·361	—0·006	—0·007	+0·006	—0·032	—0·043				
7. Potassjum Sulphate	2·344	—0·023	—0·024	—0·011	*—0·049*	*—0·060*	—0·017			
8. Ammonnium sulphate +sper . .	2·430	*+0·063*	*+0·062*	*+0·075*	+0·037	+0·026	*+0·069*	*+0·086*		
9. Ammonium sulphate +super. +pot. sulph.	2·411	+0·044	+0·043	*+0·056*	+0·018	+0·007	*+0·050*	*+0·067*	—0·019	
10. Farmyard manure	2·421	*+0·054*	*+0·053*	*+0·066*	+0·028	+0·017	*+0·060*	*+0·077*	—0·009	+0·010

For five per cent point the differences must exceed 0·0463752.

Effective manures gave definite increases in grain weight, while the effect of other manures were not significant. In both paddy and husked rice, comparison shows that the result of 1929-30 agrees with the result of 1931-32 though in both cases the z-tests failed.

Analysis for the three years combined is given in Table L.

TABLE L

Analysis of variance (weight of husked rice) (Three years combined)

Due to	Degrees of freedom	Sum of squares	Mean square	½ Log$_e$	z
Years . . .	2	0·176709	0·088354	3·3150	2·3082
Replications . 3 Interaction between years and replication . 6	9	0·019637			
Treatments . .	9	0·139093	0·015454	2·5202	1·5134
Residual . . .	99	0·074140	0·000749	1·0068	
Total .	119	0·409579			

Five per cent value of z = 0·5486 (for years)

One per cent value of z = 0·7636

Standard error of mean of four plots = 0·01513

Standard error of total of twelve plots = 0·10478

Standard error of total of ten plots = 0·095655

Standard error of total of forty plots = 0·191311

The final result for comparison between years is given in Table LI.

TABLE LI

Year	1929-30	1930-31	1931-32	S. E.
Total of 40 means . .	91·789	92·763	95·421	0·191311

There has been an increase in total husked rice weight from 1929-30 onwards and all difference must be judged significant. This does not coincide with the results for paddy weight.

The final result for comparison between treatments of different years and between treatment totals for three years is given in Table LII.

TABLE LII

Combined final result for three years (husked rice weight)

Mean of four plots	Control	Lime	Sodium nitrate	Ammonium sulphate	Superphosphate	Bone-meal	Pot. sulphate	Am. sulph. + super.	Am. sulph. + super + pot. sulph.	F. Y. M.	S. E.
1929-30	2·267	2·280	2·257	2·293	2·296	2·273	2·269	2·311	2·372	2·328	0·01513
1930-31	2·293	2·275	2·305	2·360	2·335	2·310	2·285	2·345	2·367	2·315	
1931-32	2·367	2·368	2·355	2·393	2·404	2·361	2·344	2·430	2·411	2·421	
Total for three years . .	27·710	27·696	27·668	28·186	28·143	27·777	27·592	28·342	28·603	28·256	0·10478

The difference between the same treatment in different years is in most cases significant, especially between the first year and the third year of the experiment.

Comparing the totals ammonium sulphate, superphosphate, their combinations and farmyard manure gave effective responses, while the others did not.

XIII. EFFECT OF MANURE ON THE SIZE OF GRAIN

The data for calculation were obtained from the Permanent Manurial Experiment. The measurements are the means of 100 grains.

The results (for one year only, 1931-32) are shown in Tables LV, LVI, LVII and LVIII.

TABLE LV

Length of paddy grains in mm, Ngasein, 2104

Treatment	Mean length of paddy grain in mm.	Percentage increase or decrease	Fisher's *t*
Control	8·3448	+0·03955	0·12378
Lime	8·3481		
Control	8·3210	+0·31370	1·26840
Sodium nitrate	8·3471		
Control	8·3155	+0·80570	2·34530
Ammonium sulphate	8·3825		
Control	8·3181	+0·61790	1·52700
Superphosphate	8·3695		
Control	8·3240	+0·42170	1·51340
Bone-meal	8·3591		
Control	8·3373	+0·25070	0·68900
Potassium sulphate	8·3582		
Control	8·3293	+0·64230	*3·04850*
Ammonium sulphate + superphosphate.	8·3828		
Control	8·3262	+0·74220	*3·58200*
Ammonium sulph.+super+pot.	8·3880		
Control	8·3306	+0·67580	1·78900
Farmyard manure	8·3869		

Five per cent value of *t* = 2·4470

All the manures have increased the length of paddy, but only two treatments give significant results. Ammonium sulphate alone seemed to have a large effect though statistically not definite, but the addition of other slightly effective manures have increased the length definitely.

TABLE LVI

Breadth of paddy grains in mm. (Ngasein 2104)

Treatments	Mean breadth of paddy in mm.	Percentage increase or decrease	Fisher's *t*
Control	3·3638	+0·27945	0·5562
Lime	3·3732		
Control	3·3666	+0·11880	0·42215
Sodium nitrate . . .	3·3706		
Control	3·3770	+0·29908	1·93020
Ammonium sulphate . .	3·3871		
Control	3·3790	+0·23380	1·22800
Superphosphate . . .	3·3869		
Control	3·3746	—0·01778	0·10223
Bone-meal	3·3740		
Control	3·3805	—0·08579	0·15960
Potassium sulphate . .	3·3776		
Control	3·3843	+0·39594	1·80480
Ammonium sulphate + superphosphate.	3·3977		
Control	3·3803	+0·75920	*2·75340*
Ammonium sulphate + super + pot. sulphate.	3·4060		
Control	3·3747	+0·71120	*2·47740*
Farmyard manure . . .	3·3987		

Five per cent value of t = 2·4470

Only two treatments definitely affected the breadth of paddy. Potassium sulphate and bone-meal reduced the breadth, but not significantly. The combination of three manures had a definite effect on both the length and breadth of paddy grains.

TABLE LVII

Length of husked rice in mm. (Ngasein)

Treatments	Mean length of husked rice in mm.	Percentage increase or decrease	Fisher's *t*
Control	5·9182	+0·3565	0·9069
Lime	5·9373		
Control	5·9183	+0·3481	1·9294
Sodium nitrate . . .	5·9389		
Control	5·9142	+1·3425	*2·5461*
Ammonium sulphate . .	5·9936		
Control	5·9227	—0·2972	0·5709
Superphosphate . . .	5·9051		
Control	5·9333	—0·0792	0·2480
Bone-meal	5·9286		
Control	5·9194	—0·3581	1·3944
Potassium sulphate . .	5·8982		
Control	5·9145	+0·9975	*3·8012*
Ammonium sulphate + superphosphate.	5·9735		
Control	5·9213	+0·5421	0·9680
Ammonium sulphate + super + pot. sulphate.	5·9534		
Control	5·9302	+0·4924	1·3235
Farmyard manure . . .	5·9594		

Five per cent value of *t* = 2·4470

Superphosphate, bone-meal and potassium suplphate reduced the length, though the decreases are not significant. Ammonium sulphate alone showed the highest percentage increase over the control. By the addition of superphosphate, the increase in length was reduced. The increase in length was further reduced by the addition of potassium sulphate. The additive effect of the three manures was definite.

TABLE LVIII

Breadth of husked rice in mm. (Ngasein 2104)

Treatments	Mean breadth in mm.	Percentage increase or decrease	Fisher's t
Control	2·8441	+0·41840	0·7012
Lime	2·8560		
Control	2·8507	+0·16840	0·2617
Sodium nitrate . . .	2·8555		
Control	2·8513	+0·9259	1·6163
Ammonium sulphate . .	2·8777		
Control	2·8498	+0·5931	1·1327
Superphosphate . . .	2·8667		
Control	2·8493	−0·2492	0·6995
Bone-meal	2·8422		
Control	2·8484	+0·3862	0·6735
Potassium sulphate . .	2·8594		
Control	2·8608	+0·9648	1·7742
Ammonium sulphate + superphosphate.	2·8884		
Control	2·8683	+0·7809	2·0306
Ammonium sulphate + super + pot. sulphate.	2·8907		
Control	2·8631	+0·6986	1·7804
Farmyard manure . . .	2·8831		

Five per cent value of t = 2·4470.

None of the treatments was definitely effective on the breadth of husked rice. Ammonium sulphate and its combinations increased the breadth, but the increases cannot be judged significant. On the whole there is distinct evidence that those manures which are effective in increasing grain yields also cause increases in the mean weights of grains. It has also been shown by Rhind [1930, 1932] that these manures tend to increase the liability to breakage of grain when the milling is carried out in a treadle pounder (Burmese *Moung*).

XIV. EFFECT OF MANURE ON THE DIFFERENT PARTS OF THE PADDY GRAIN

Information as to how manures affect the different parts of the paddy grain was obtained by subtracting from the paddy weight, the husked and polished rice weights. The milling was done according to the method described by Rhind and U Tin [1933] with the apparatus described by Hayes [1932]. The results for 1929-30 and 1930-31 are shown in Tables LIII and LIV. Husk is estimated by difference of paddy and husked rice weights and bran by difference between husked and polished rice weights.

TABLE LIII

Effect of manures on weights of husk, bran, and polished rice (Ngasein) *1929-30*

Treatments	Husk			Bran			Polished rice		
	Control	Treated	Fisher's *t*	Control	Treated	Fisher's *t*	Control	Treated	Fisher's *t*
1. Lime	0·670 Increase	0.685 (+0·015)	1·2060 (N)	0·148 Decrease	0·137 (—0·011)	0·8215 (N)	2·127 Increase	2·144 (+0·017)	1·0600 (N)
2. Sodium nitrate	0·688 Decrease	0·675 (—0·013)	0·5167 (N)	0·150 Increase	0·170 (+0·020)	0·8468 (N)	2·122 Decrease	2·087 (—0·035)	2·0000 (N)
3. Ammonium sulphate	0·665 Decrease	0·656 (—0·009)	0·3353 (N)	0·148 Decrease	0·129 (—0·019)	1·3600 (N)	2·122 Increase	2·164 (+0·042)	4·9500 (S)
4. Superphosphate	0·647 Decrease	0·646 (—0·001)	0·0319 (N)	0·151 Increase	0·156 (+0·005)	0·3707 (N)	2·109 Increase	2·140 (+0·031)	1·7500 (N)
5. Bone-meal	0·681 Decrease	0·680 (–0·001)	0·1280 (N)	0·155 Decrease	0·117 (—0·038)	1·7640 (N)	2·112 Increase	2·156 (+0·044)	1·3730 (N)
6. Potassium sulphate	0·664 Increase	0·666 (+0·002)	0·0559 (N)	0·147 Neither increase nor decrease	0·147	0	2·116 Increase	2·122 (+0·006)	0·3661 (N)
7. Ammonium sulphate + superphosphate	0·631 Increase	0·688 (+0·057)	1·6560 (N)	0·138 Increase	0·147 (+0·009)	0·5738 (N)	2·116 Increase	2·164 (+0·048)	3·1000 (S)
8. Ammonium sulphate + superphosphate + pot. sulphate.	0·635 Increase	0·664 (+0·029)	1·2300 (N)	0·136 Increase	0·173 (+0·037)	2·5070 (S)	2·126 Increase	2·197 (+0·071)	2·6360 (S)
9. Farmyard manure	0·650 Increase	0·683 (+0·038)	1·3900 (N)	0·145 Increase	0·153 (+0·008)	0·6210 (N)	2·133 Increase	2·175 (+0·042)	1·4300 (N)

(N) and (S) in the table mean 'not significant' and 'significant'.
Five per cent value of *t* = 2·4470·

TABLE LIV

Effect of manures on weights of husk, bran and polished rice (Ngasein) *1930-31*

Treatments	Husk			Bran			Polished rice		
	Control	Treated	Fisher's *t*	Control	Treated	Fisher's *t*	Control	Treated	Fisher's *t*
1. Lime	0·605 Decrease	0·587 (—0·018)	0·4452 (N)	0·147 Neither decrease nor increase	0·147	...	2·127 Neither decrease nor increase	2·127	...
2. Sodium nitrate . . .	0·627 Decrease	0·607 (—0·020)	0·5810 (N)	0·151 Increase	0·155 (+0·004)	0·2389 (N)	2·154 Decrease	2·150 (—0·004)	0·3972 (N)
3. Ammonium sulphate . .	0·624 Increase	0·647 (+0·023)	0·6781 (N)	0·157 Decrease	0·150 —(0·007)	0·5885 (N)	2·156 Increase	2·210 (+0·054)	4·9720 (S)
4. Superphosphate . . .	0·604 Decrease	0·592 (—0·012)	0·5610 (N)	0·165 Neither decrease nor increase	0·165	...	2·129 Increase	2·170 (+0·041)	2·3450 (N)
5. Bone-meal	0·576 Increase	0·647 (+0·071)	2·1270 (N)	0·165 Decrease	0·155 (—0·010)	0·4900 (N)	2·144 Increase	2·155 (+0·011)	0·3520 (N)
6. Potassium sulphate . .	0·607 Increase	0·617 (+0·025)	0·7404 (N)	0·132 Decrease	0·140 (+0·008)	0·4484 (N)	2·145 Neither decrease nor increase	2·145	...
7. Ammonium sulphate + super. .	0·590 Increase	0·615 (+0·025)	1·5400 (N)	0·144 Decrease	0·137 (—0·007)	0·5362 (N)	2·144 Increase	2·207 (+0·063)	4·3380 (S)
8. Ammonium sulphate + super- + potassium sulphate.	0·601 Increase	0·622 (+0·021)	0·8210 (N)	0·142 Increase	0·155 (+0·013)	0·8056 (N)	2·162 Increase	2·212 (+0·050)	2·8110 (S)
9. Farmyard manure . . .	0·632 Decrease	0·617 (—0·015)	0·7247 (N)	0·144 Increase	0·165 (+0·021)	1·0480 (N)	2·137 Increase	2·150 (+0·013)	0·5523 (N)

(N) and (S) in the table mean 'not significant' and 'significant'.
Five per cent value of $t = 2{\cdot}4470$.

In neither year has any treatment shown a significant effect on the weight of husk nor on the weight of bran except the treatment No. 9 (a combination of three manures) in the year 1930-31. Ammonium sulphate and its combinations have a definite effect on the weight of polished rice in both years. Therefore the increase in weight of paddy and husked rice by the addition of manure was due more to the increase in weight of rice than to the increase in the other parts. The addition has thus been to the most useful part of the fruit.

XV. DIFFERENCES IN GRAIN SIZE DUE TO LOCALITY

It has been found that within the same administrative circle one variety of paddy from different localities differs in length and breadth to a considerable extent. The author is indebted to U Shwe Yin, Dip. Agri., Senior Agricultural Assistant, Myaungmya, for the following data for the variety *Emata A 26-3*, a translucent-grained type. The paddy was grown at eleven centres within the Irrawaddy Circle (Delta). The figures are given in Table LIX.

TABLE LIX

Mean length of grain, standard error and mean variance in mm. (Emata A 26-3)

Localities	Tagundaing	Letthama	Central Farm, Myaungmya	Pandabut	Sangin	Pyapon	Mayan	Bassein	Yegyi	Wakema	Myaungmya
Mean . . .	7·349	7·310	7·409	7·280	7·379	7·460	7·286	7·333	7·338	7·365	7·424
S. E. of mean .	0·02605	0.03263	0·02727	0·02694	0·03141	0·02996	0·03111	0·03033	0·03408	0·02949	0·03024
Variance of mean .	0·0006787	0·0010647	0·0007439	0·0007257	0·0009863	0·0008977	0·0009677	0·0009198	0·0011610	0·0008704	0·0009149

Standard error of the differences of the means = 0.03141

To test the homogeneity of the whole set of 1100 measurements they are analysed below in Table LX.

TABLE LX

Analysis of variance, grain lengths of Emata A 26-3

	Degrees of freedom	Sum of squares	Mean square	S. D.	$\log_e$ S. D.
Within localities .	1089	99·3077	0·09119	0·30197	3.6514
Between localities	10	0·030239	0·00302	0·05499	1·7046
Total . .	1099	99·3379		Difference	=1·9468=z

Standard deviation of z is 0·2246

The difference observed is significant, therefore the whole set of values appears to be non-homogeneous with a variance of about 0·090388. The standard error of means=0·03019.

Variation in breadth of grains from A 26-3 *grown at eleven different localities.*

The mean and standard error of the mean are given in Table LXI.

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TABLE LXI

Mean breadth of grain, standard error and mean variance in mm. (Emata A 26-3)

Localities	Tagundaing	Letthama	Central Farm, Myaungmya	Pandabut	Sangin	Pyapon	Mayan	Bassein	Yegyi.	Wakema.	Myaungmya
Mean . . .	2·592	2·554	2·546	2·598	2·619	2·606	2·578	2·635	2·597	2·620	2·589
S. E. of mean .	0·01004	0·00863	0.00851	0·00914	0·00930	0.00978	0·00994	0·00861	0·00892	0·00978	0·01036
Variance of mean .	0·0001010	0·0000745	0·0000725	0·0000836	0·0000871	0·0000957	0·0000988	0·0000742	0·0000796	0·0000957	0·0001075

Standard error of the differences of the means = 0·00985

Analysis of variance to test the homogeneity is given in Table LXII.

Table LXII

Analysis of variance, grain breadths of Emata A 26-3

Due to	Degrees of freedom	Sum of squares	Mean square	S. D.	$\log_e$ (S. D.)
Within localities .	1089	9·702000	0·008909	0·09438	2·2447
Between localities .	10	0·007340	0·000734	0·02709	0·9966
Total . .	1099	9·709340		Difference	=1·2481

Standard deviation of z = 0·2246

Like length of grains, the majority of the mean differences in breadth are significant, and the whole set of values seems to be non-homogeneous with a variance of about 0·008833. The S. E. of means = 0·009438.

Difference in variability due to localities

Analyses for grain length and breadth are given in Tables LXIII and LXVIV.

Table LXIII

Analysis of variance of variabilities for length (A 26-3)

Due to	Degrees of freedom	Sum of squares	Mean square	$\frac{1}{2}\log_e$ (mean square)	$\frac{1}{n}$
Tagundaing . . .	99	6·7886	0·06855	0·96246	0·010101
Letthama . . .	99	10·6400	0·10747	1·18730	0·010101
Central Farm, Myaungmya	99	7·4380	0·07513	1·00870	0·010101
Pandabut . . .	99	7·2556	0·07330	0·99600	0·010101
Sangin	99	9·8626	0·09962	1·14930	0·010101
Pyapon	99	8·9766	0·09067	1·10230	0·010101
Mayan	99	9·6771	0·09775	1·14000	0·010101
Bassein	99	9·1977	0·09291	1·11450	0·010101
Yegyi	99	11·6122	0·11729	1·23120	0·010101
Wakema	99	8·7042	0·08792	1·08700	0·010101
Myaungmya . . .	99	9·1491	0·09242	1·11190	0·010101

Standard deviation of z = 0·1004

TABLE LXIV

Analysis of variance of variabilities for breadth (A 26-3)

Due to	Degrees of freedom	Sum of squares	Mean square	$\frac{1}{2}$ Log$_e$ (mean square)	$\frac{1}{n}$
Tagundaing . . .	99	1·010	0·010202	1·1613	0·010101
Letthama . . .	99	0·745	0·007525	1·0088	0·010101
Central Farm, Myaungmya	99	0·725	0·007323	0·9955	0·010101
Pandabut . . .	99	0·836	0·008444	1·0670	0·010101
Sangin	99	0·871	0·008798	1·0872	0·010101
Pyapon	99	0·957	0·009666	1·1343	0·010101
Mayan	99	0·988	0·009980	1·1452	0·010101
Bassein	99	0·742	0·007495	1·0070	0·010101
Yegyi	99	0·796	0·008040	1·0422	0·010101
Wakema	99	0·957	0·009666	1·1343	0·010101
Myaungmya . . .	99	1·075	0·010859	1·1925	0·010101

Standard deviation of z = 0·1004

Differences in variability in length are significant in a few cases, while in breadth the difference is definite only between the paddies grown at the Central Farm, Myaungmya, and Myaungmya. Therefore the variabilities in length and breadth due to localities cannot be judged significant on these data.

XVI. DISCUSSION

The results presented in this paper reveal several interesting features on the developmental variation in the paddy grain in relation to various environmental factors. This variation in grain dimensions, though not large, is of such a magnitude as to be of importance in milling.

It has been shown that in order to get a representative sample, it is necessary to take the measurements of at least 100 grains. Lord [1929] found that in order to get a representative sample, measurement could be restricted to twenty grains only. Ramiah [1933] concluded from his experiment, that the measurement of six grains from the top and middle portions of the panicle, was sufficient. The present experiment, however, definitely shows that little reliance can be placed on a random sample which consists of fewer than 100 grains.

As regards the variation within a panicle, Ramiah [1933] mentions only the presence of a higher proportion of ill-filled and half-set grains in the lower portion of the panicle, while van der Stok [1912] found that the mean weight decreases downward on the panicle. The latter's finding has been confirmed in this paper. Size, which generally depends upon weight, shows a tendency to decrease downwards, but comparison between mean lengths of grains of the top and middle portions did not show a singificant difference.

The conclusion arrived at by Ramiah and Parthasarathi [1933] that grains in different tillers (panicles) of the same plant do not vary significantly in size, is not confirmed. In the present experiments on both the two pure-line paddies significant differences have been obtained not only between one panicle and another of the same plant in the majority of comparisons, but also between one plant and another of the same paddy. Therefore variations within a plant and within a variety are definite even in stabilized types which have been grown in pure culture for a number of years in the same place under identical conditions.

The effect of spacing on the size of grain is not definite, but there are indications showing that grains tend to be longer with closer spacing. Of the two experiments carried out here, in one, size of grain has shown a definite response to spacing.

On the effect of various manures tested, ammoniacal fertilizers alone and in combination with other artificials cause a true increase in mean whole grain weight. Significant increase of the weight of grain without husk is caused only by the addition of two fertilizers together, *viz.*, ammonium sulphate and superphosphate. Regarding the effect on the polished rice, the most important part of the fruit, ammonium sulphate and its combinations produce significant increases. Husk and bran are only affected slightly by the addition of fertilizers. The influence of nitrogenous fertilizers on wheat have been studied by Engledow and Ramiah [1930] and it has been found that grain size is much affected. Results obtained here agree with their findings. Paddy grain dimensions are positively affected by the addition of ammonium sulphate in combination with superphosphate and potassium sulphate.

In the study of the influence of different harvesting dates, the results obtained here show that grains tend to become smaller with later harvesting, but detailed investigation is necessary to properly assess the role of ripening on the modification of grain size.

Influence of soil conditions and season on grain size has not received the attention of many investigators working on paddy. Ramiah and Parthasarathi [1933] in their paper pointed out that grain size is liable to be affected by different soil conditions and seasons. In this paper, results are given to show that soil and season have definite effects on the size of grain.

The effect of various environmental causes on the variability of paddy grain length, which is of some importance for plant breeders, has never been studied before. Variability, the amount of variance, is much affected by small alterations of the environment. The variability of one strain may or may not be the same as that of another. The variability of two different paddies may not differ significantly, but the variability of the same strain may be altered considerably by changes in spacing, harvesting date, season and soil.

This work has been carried out under the supervision of Mr. D. Rhind, Economic Botanist, Burma, to whom the author is greatly indebted for his suggestions and assistance in writing this paper.

XVII. SUMMARY

1. Figures are given to show that samples of less than 100 grains cannot be relied on to give a representative grain measurement.

2. It is shown that within a panicle grain length and weight decreases from the top downwards and that the lower part of a panicle bears more unfilled grains than the upper.

3. Grain length may differ significantly between panicles of the same plant.

4. The extent to which pure lines may vary is itself a variable character.

5. In the variety *Taungdeikpan* the wider the spacing the shorter the grains tend to be. *Ngasein* did not show this effect clearly.

6. *Ngasein* has shown a decrease in variability at two ft. × two ft. spacing as compared to one ft. × one ft. while *Taungdeikpan* showed an increase at the wider spacing.

7. Length and breadth of *Ngasein* grains were reduced by later harvesting dates.

8. Grain weight of *Ngasein* was found to be liable to significant variation from year to year and grain length of *Taungdeikpan* showed a similar effect.

9. In *Ngasein* fertilizers have affected grain weight and dimensions. In general those fertilizers which give substantial increases in yield have given significant increases in grain size. In the case of combined manures the effect seems to be additive.

10. The increase in grain weight caused by fertilizers is shown to be due mainly to increase in the endosperm (rice) and not to the husk or bran.

11. Grain length and breadth of the pure line *A26-3* from eleven localities in Lower Burma are shown to differ significantly from place to place. The amount of variability does not differ significantly from place to place.

REFERENCES

Beale, R. A. (1927). *Agric. Res. Inst. Pusa Bull. No.* **157**.

Engledow, F. L. and Ramiah, K. (1930). *J. Agric. Sci.* **20**, Pt. II.

Hayes, A. (1932). *Agric. and Livestock in Ind.* **2**, 162.

Lord, L. and Abeyesundra, L. (1929). *Ann. Roy. Bot. Gard. Peradeniya*, **11**, 2.

Ramiah, K. and Parthasarathi, N. (1933). *Ind. J. Agric. Sci.* **3**, Pt. V.

Rhind, D. (1930). *Report of the Economic Botanist, Burma*, p. 3.

——— (1932). *Report of the Economic Botanist, Burma*, p. 5.

Rhind, D. and U Tin (1933). *Ind. J. Agric. Sci.* **3**, Pt. IV.

Sethi, R. L. and Saxena, B. P. (1930). *Mem. Dept. Agric. Ind., Bot. Ser.* **18**, No. 6.

Van der Stok, E. (1912). *Die Züchtung der landwirtschaftlichen kulturpflanzen, C. Fruwirth*, Vol. 5.

STATISTICAL NOTES FOR AGRICULTURAL WORKERS

No. 17.—ON THE INFLUENCE OF SHAPE AND SIZE OF PLOTS ON THE EFFECTIVE PRECISION OF FIELD EXPERIMENTS WITH *JUAR* (*ANDROPOGON SORGHUM*)

BY

R. K. KULKARNI, B.Ag.,

Superintendent, Cereal Breeding Station, Niphad, Dist. *Nasik*

AND

SUBHENDU SEKHAR BOSE,

Statistical Laboratory, Calcutta,

IN CONJUNCTION WITH

P. C. MAHALANOBIS

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Introduction

The efficiency of a field experiment depends on the standard error of the different estimates involved in the test, and it is therefore necessary that the experimental arrangement should be designed in such a way as to ensure the highest possible precision.

Among the many factors that contribute to the magnitude of the errors in agricultural field experiments the following three are of considerable importance :—

(1) Shape and size of the individual plot.
(2) Shape and size of the Block Division (for elimination of soil heterogeneity).
(3) The position and orientation of the plots and of the blocks in the experimental field.

A certain amount of work on the influence of the shape and size of individual plots on the magnitude of errors has been done both in India and abroad. The crops chosen were generally the cereals, potatoes or sugar-beets, In the United States, Stephens and Vinall [1928] working at Chillicothe-Texes in 1928 found three or four replications of 1/40 acre and 1/80 acre plots fully adequate for field tests with sorghum. Swanson [1930] has shown that the standard error of an experiment does not appreciably decrease after the plot size has increased to 1/25 acre ; he also observed that longer plots gave higher precision than square plots of equal area. Ligon [1930] has calculated with data on cotton grown on the Oklahoma Experimental Station that for optimum accuracies, the length of a plot did not exceed 100 feet.

In India, a uniformity trial with sugarcane (1933) was analysed and the results showed 1/24 acre (151′·3 × 12′) to be the optimum area of plots for this crop. A more extensive experiment on rice at Chinsurah [Mahalanobis *et al*, 1934] (Bengal) Government Farm (2) showed the optimum area for rice to be 1/60 acre. In Assam [Mitra and Ganguli, 1934] again, the optimum area for rice was very nearly the same.

It is obvious that the optimum size is determined by the distribution of fertility contours in the given piece of land, and hence is likely to vary from place to place. But if the experimental site is kept fixed, the results of uniformity trials in any one year may be a valuable guide for work in the succeeding year, provided of course that the fertility distribution remains more or less the same from year to year. In the present investigation an attempt has been made to study these questions with the help of the results of an experiment with *Juar* conducted in Sholapur district for three consecutive years (1930-33).

EXPERIMENTAL DETAILS

One acre of land (290′.4 × 150′) was chosen in the midst of a bigger area (plot No. 13 on the Mohol Plot) for sowing *Maldandi juar*, a variety extensively grown all over the Sholapur district. It was harvested in plots of 1/160 acre (72 ft. 6 in. × 3 ft. 9 in.) each containing three rows of the plants 15 in. apart. The 160 plots were arranged in forty rows of four columns, and the yields were measured in tolas. The plot division was kept intact for three years, and the yields of the 160 plots are available for three consecutive harvests. The original data are given in Appendix I.

NATURE OF DISTRIBUTION OF EXPERIMENTAL RESULTS

It has been claimed by the statistical workers at Rothamsted on the evidence of the experimental results of uniformity trials that the usual yield data obey approximately the Normal law of distribution. The data for rice yields at Chinsurah Farm have also broadly confirmed this result ; the deviations from the Normal distribution although significant are not large. In view of the importance of the question, the distribution of the *juar* yields has been investigated in detail. The frequency constants are given in Table I.

TABLE I

Frequency constants of the distribution of juar *with their standard errors*

	1930-31	1931-32	1932-33
n	160	160	160
Mean	$116\cdot2875 \pm 2\cdot3851$	$67\cdot2250 \pm 1\cdot8765$	$126\cdot3688 \pm 2\cdot5501$
Standard deviation	$30\cdot1695 \pm 1\cdot6865$	$23\cdot7365 \pm 1\cdot3269$	$32\cdot2568 \pm 1\cdot8032$
β_1	$0\cdot7930 \pm 0\cdot2937$	$0\cdot4339 \pm 0\cdot4005$	$0\cdot0802 \pm 0\cdot2123$
β_2	$3\cdot3107 \pm 0\cdot5355$	$3\cdot9002 \pm 1\cdot5594$	$4\cdot0205 \pm 2\cdot1994$

The distributions seem to be of the non-normal type ; but the values of β_1 and β_2 being based on only 160 observations have large standard errors. It is thus not possible to assert with these sets of observations that the distributions of the yields are significantly different from the normal type. Only in the first year, is the value of β_1 appreciably different from 0, *i.e.*, the skewness is significant In the two later years however it is fairly symmetrical. The values of β_2 although numerically greater than three in all the cases, cannot be considered to be different from three in the light of the standard errors. The observed distributions therefore may be taken to be a sample from a normal population. It may however be added that Egon Pearson* [1929] and others have shown on the basis of experimental sampling that the usual tests of significance are not invalidated for slight divergences from normal distribution.

ANALYSIS OF RESULTS

In analysing the data, fifteen different shapes of plot have been considered. It will be observed from the data given in Appendix I that heterogeneity is more marked between columns than between rows of same area. Thus in 1930-31, the estimated variance of the means of four columns is 512.6, while that of the means of four blocks (of ten rows each) is 102·5. The columns, singly and sometimes by twos have therefore been treated as blocks for eliminating soil heterogeneity and R. A. Fisher's method of analysis of variance has been used throughout for calculating experimental errors.

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* Egon S. Pearson assisted by Adyanthaya and others studied by actual sampling experiments the frequency distributions of Student's z, the usual test of significance between two observed means drawn from a number of non-normal symmetrical and skew populations given by (1) $\beta_1 = 0, \beta_2 = 2\cdot5$, (2) $\beta_1 = 0, \beta_2 = 4\cdot12$, (3) $\beta_1 = 0, \beta_2 = 7\cdot07$ (4) $\beta_1 = 0\cdot2, \beta_2 = 3\cdot30$ (5) $\beta_1 = 0\cdot5, \beta_2 = 3\cdot73$. The sizes of samples were 2, 5, 10 and 20, respectively. As a result of two series of tests, *viz.*, the single and two sample tests, it has been shown that in the former case 21 tests of goodness of fit for z gave a mean value of 0·463 and in the latter case nine values of P gave a mean of 0·332. Pearson remarks that in these ranges of β_1 and β_2 ' there will not in practice be a danger of any serious loss of control ' with regard to the hypothesis being rejected when it is in fact true. It will be noticed that the observed values in the present series of field experiments mostly lie within the range covered by Pearson's work.

The residual standard deviations between plots are shown in Table II and the standard deviations expressed as percentages of mean yields in Table III for different shapes and sizes of plots for the year 1930-31. Corresponding figures for 1931-32 and for 1932-33 are given in Tables IV—VII.

TABLE II

Standard deviation of plots in tolas, 1930-31

Breadth (unit= 3·75 ft.)	(a) Before elimination of block differences			(b) After elimination of block differences	
	Length (unit = 72·5 feet)				
	1	2	4	1	2
1	30·17	42·46	54·27	21·66	33·75
2	58·33	81·98	103·20	40·68	63·86
4	112·04	156·21	189·00	75·19	117·71
5	139·41	196·71	239·71	93·53	149·43
10	262·09	368·30	405·10	162·09	262·65

TABLE III

Standard deviation expressed as percentage of mean, 1930-31

	(a) Before elimination of block differences			(b) After elimination of block differences	
	1	2	4	1	2
1	25·94	18·26	11·67	18·63	14·51
2	25·08	17·62	11·09	17·49	13·73
4	24·09	16·79	10·16	16·16	12·65
5	23·98	16·92	10·31	16·09	12·85
10	22·54	15·84	8·71	13·94	11·29

TABLE IV

Standard deviation of plots in tolas, 1931-32

	(*a*) Before elimination of block differences			(*b*) After elimination of block differences	
	1	2	4	1	2
1	23·74	35·38	55·13	19·76	30·90
2	45·16	67·74	105·2	36·96	58·52
4	86·78	130·97	202·1	70·48	112·47
5	106·54	161·80	250·6	86·33	139·00
10	197·79	311·75	485·3	168·23	269·62

TABLE V

Standard deviation expressed as precentage of mean, 1931-32

	(*a*) Before elimination of block differences			(*b*) After elimination of block differences	
	1	2	4	1	2
1	35·31	26·31	20·50	29·39	22·98
2	33·59	25·20	19·56	27·49	21·76
4	32·27	24·35	18·79	26·21	20·91
5	31·70	24·07	18·64	25·68	20·67
10	29·42	23·19	18·04	25·02	20·05

TABLE VI

Standard deviation of plots in tolas, 1932-33

	(*a*) Before elimination of block differences			(*b*) After elimination of block differences	
	1	2	4	1	2
1	32·26	50·36	49·21	29·83	46·95
2	57·31	95·15	86·44	52·10	88·30
4	108·76	185·87	171·3	99·31	173·66
5	136·86	230·69	191·6	126·44	216·52
10	260·34	448·50	393·1	250·11	432·86

TABLE VII

Standard deviation expressed as percentage of mean, 1932-33

	(a) Before elimination of block differences			(b) After elimination of block differences	
	1	2	4	1	2
1	25·53	19·93	9·74	23·61	18·58
2	22·68	18·82	8·55	20·61	17·47
4	21·52	18·39	8·47	19·65	17·18
5	21·66	18·25	7·58	20·01	17·13
10	20·60	17·74	7·78	19·79	17·13

It will be seen that the standard deviation does not increase proportionately to the increase of the size of the plot, in fact as the area of the individual plots is increased, the percentage standard deviation diminishes but this decrease is more rapid for plots of increased lengths than for increased breadths.

Thus, if unit of length ($=72\cdot5$ feet) $= l$

and unit of breadth ($= 3\cdot75$ feet) $= b$

we find the following results for 1930-31, without eliminating soil differences.

TABLE VIII

Standard deviations expressed as percentage per plot of different shapes

Size of plot	S. D.	Size of plot	S. D.
$(2l) \times (b)$	18·26	$(4l) \times (b)$	11·67
		$(2l) \times (2b)$	17·62
$(l) \times (2b)$	25·08	$(l) \times (4b)$	24·09

Thus, highly narrow strips of plots (length much greater than breadth) lead to greater precision than plots of same area but much wider and not so narrow. The same result has been obtained by a number of workers ; Christidis [1931] has shown on the basis of certain theoretical considerations, that plots should be as long and as narrow as possible in order to reduce the effect of soil heterogeneity ; this " of course, within the limits set by different practical considerations, amongst which convenience, competition, and accurate measurement of width appear to be the most important ".

In the present investigation, the results of all the three years corroborate Christidis's conclusions, as can be seen from Tables III, V and VII for the years 1930-31, 1931-32 and 1932-33 respectively. The residual standard deviation has steadily decreased in all three seasons up to the largest area, for each individual width.

SOIL HETEROGENEITY

It is now generally accepted that soil heterogeneity is a characteristic of all fields and one of the objects of field designs is to eliminate, by local control, this source of variation as far as possible. It will be interesting therefore to investigate how far the precision of the experiment has been increased in the present design by using Fisher's method of Randomised blocks.

A comparison of the results given in the two portions.

(*a*) before elimination of block differences, and
(*b*) after elimination of block differences

in Tables II—VII will show the actual improvement achieved. Thus in 1930-31, for a plot size ($1l \times 10b$), the S. D. before block elimination is 262·09 tolas per plot while, after this elimination, this is reduced to 162·09 tolas per plot. It is true that the magnitude of the reduction is not the same for plots of all sizes, but practically in every case the block elimination has appreciably improved the precision of comparison.

We have seen that the percentage standard deviation decreases steadily as the size of the plot is increased. But for a given size of the experimental field, an increase in plot size also means a reduction in the number of replications. Thus while the error of the experiment is reduced by the decrease in the percentage standard deviation due to increase of plot size, it is at the same time increased by the loss in the number of replications.

It is clear therefore that in order to determine the optimum size of the plot, it is necessary to take both these factors into consideration. A suitable criterion is obtained by multiplying the percentage standard deviation of each plot size by the square root of the number of ultimate plot units which the plot contains. The final standard errors (corrected for plot size and number of replications) are shown in Tables IX—XI. These tables are now comparable for the effective precision of the experiment.

TABLE IX

Percentage standard error corrected for size of plot and number of replications, 1930-31

	(a) Before elimination of block differences			(b) After elimination of block differences	
	1	2	4	1	2
1	25·94	25·82	23·34	18.63	20.52
2	35·46	35·24	31·36	24.73	27.46
4	48·18	47·48	40·64	32.32	35.77
5	53·62	53·50	46·11	35.98	40.63
10	71·27	70·84	55·08	44.08	50.49

TABLE X

Percentage standard error corrected for size of plot and number of replications, 1931-32

	(a) Before elimination of block differences			(b) After elimination of block differences	
	1	2	4	1	2
1	35·31	37·20	41·00	29·39	32·49
2	47·50	50·40	55·32	38·87	43·52
4	64·54	68·86	75·16	52·42	59·13
5	70·88	76·11	83·36	57·42	65·36
10	93·03	103·71	114·08	79·11	89·66

TABLE XI

Percentage standard error corrected for size of plot and number of replications, 1932-33

	(*a*) Before elimination of block differences			(*b*) After elimination of block differences	
	1	2	4	1	2
1	25·53	28·18	19·48	23·61	26·27
2	32·07	37·64	24·18	29·14	34·94
4	43·04	52·01	33·88	39·30	48·59
5	48·43	57·71	33·90	44·74	54·17
10	65·14	79·33	49·20	62·58	76·61

For convenience of comparison, the effective standard errors are shown in Tables XII—XIV as percentages of the corresponding standard errors of the smallest plots.

TABLE XII

Standard error expressed as percentage of standard error of the smallest plot, 1930-31

	(*a*) Before elimination of block differences			(*b*) After elimination of block differences	
	1	2	4	1	2
1	100·00	99·54	88·98	71·82	79·10
2	136·70	135·85	120·89	95·33	105·86
4	185·73	183·04	156·67	124·59	137·89
5	206·71	206·24	177·75	138·70	156·63
10	274·75	273·09	212·33	169·93	194·64

TABLE XIII

Standard error expressed as percentage of standard error of the smallest plot, 1931-32

	(a) Before elimination of block differences			(b) After elimination of block differences	
	1	2	4	1	2
1	100·00	105·35	116·11	83·23	92·01
2	134·52	142·73	156·67	110·08	123·25
4	182·78	195·01	212·85	148·45	167·46
5	200·73	215·54	236·08	162·61	185·10
10	263·46	293·71	323·07	224·04	253·92

TABLE XIV

Standard error expressed as percentage of standard error of the smallest plot, 1932-33

	(a) Before elimination of block differences			(b) After elimination of block differences	
	1	2	4	1	2
1	100·00	110·37	76·30	92·48	102·90
2	125·62	147·43	94·71	114·14	136·86
4	168·59	203·72	132·71	153·94	190·32
5	189·70	226·05	132·78	175·24	212·18
10	255·15	310·73	192·71	245·12	300·08

Two things here deserve notice. The effective precision, as observed by previous workers, generally decreases as the plot size is increased. But this is not true invariably. We find in fact that, in the present series of experiments, a plot size of $4l \times 1b$ (290′ × 3′.75) in 1930-31 and 1932-33, $2l \times 1b$, (145′ × 3′.75) in 1931-32 give the greatest precision. It appears desirable therefore to use long plots of 1/40 acre running from east to west in future experiments with *juar* on this particular field. The next best size of plots will be 145′ × 3′.75 (1/80 acre).

ANALYSIS OF CO-VARIANCE

In the foregoing analysis increased precision was obtained by block division. This procedure eliminates the soil-heterogeneity between blocks, but it is incapable of eliminating the soil differences existing between plots within the same block. Co-variance analysis is often of great help for this purpose where results for successive seasons are available, and has proved highly successful in the case of certain crops, *e.g.*, potato, sugar-beet, and tea.

In this method the correlation between the yields of two consecutive seasons is calculated, and if this correlation is statistically significant, the information for the first season is utilised for eliminating the fertility differences between plots within the same block in the second season. The improvement in precision increases naturally with the magnitude of the coefficient of correlation. In the present experiment however the residual correlations are practically negligible, as shown in Table XV.

TABLE XV

Coefficient of correlation

Year	Block	Residual
1930-31 × 1931-32	0·6250	0·1741
1931-32 × 1932-33	0·9826	+0·0392
1930-31 × 1932-33	0·7516	—0·0536

The coefficient of correlation between blocks, being based on two degrees of freedom, may be considered significant only in the case of 1931-32 and 1932-33; the other two, though high, are less than the five per cent value. The correlation between plots is not appreciable in any of the three combinations. With such insignificant correlations it is not possible to improve the precision of the experiment in subsequent years with the help of the results of the previous seasons. It is however desirable to examine whether this is true for the *juar* fields in general.

SUMMARY

Uniformity trials with *juar* (*Andropogon Sorghum*) were conducted for three successive years (1930-33) in Mohol plot in Sholapur district. A detailed statistical analysis gave the following results :—

(1) The frequency distribution of yields is not strictly normal ; the divergence from normality although statistically significant is not large.

(2) The frequency distributions were not significantly different from the normal type ; but as the sample was based on only 160 observations, this test of deviation from normality was not sufficiently precise.

(3) The systematic differences in soil-fertility were appreciably eliminated by dividing the field into two and four blocks, and the precision of the experiments was thereby improved very considerably.

(4) Long and narrow strips of plots gave greater precision than plots of same area but much wider.

(5) The standard deviation between plots decreased as the plot area in creased, but the gain in precision was less than the loss due to the reduction in the number of replications.

(6) The effective precision (corrected for size of plots and number of replications) was highest in plots of 290 ft. × 3·75 ft. (or 1/40 acre). The next best plot was 145 ft. ×3·75 ft. (or 1/80 acre).

(7) The yield of plots within the same block did not show appreciable correlation from year to year, so that the method of analysis of co-variance failed to give increased precision in succeeding years.

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REFERENCES

Stephens, J. C. and Vinall, H. N. (1928). *J. Agric. Res.* **37**, Part II.

Pearson, E. S. & others (1929). *Biom.* **21**, 259-86.

Ligon, L. L. (1930). *J. Amer. Soc. Agron.* **22**, Part VIII.

Swanson, A. F. (1930). *J. Amer. Soc. Agron.* **22**, Part X.

Christidis, B. Z. (1931). *J. Agric. Sci.* **21**, 14-37.

Vaidyanathan, M. (1933). *Sci. Cong. Abs. Agric. Sec., Abs. No. 1.*

Mahalanobis, P. C. and others (1934). *Sci. Cong. Abs. Agri . Sec., Abs. No. 8.*

Mitra, S. K. and Ganguli, P. M. (1934). *Sci. Cong. Abs. Agric. Sec., Abs. No. 9.*

APPENDIX 1

Sketch Map I, 1930-31

Yield of grain in "tolas" of original 160 plots of one acre during the year 1930

144	183	142	144
171	135	124	132
156	145	121	107
134	122	134	80
180	122	137	99
172	95	122	87
175	117	94	98
186	114	89	70
174	112	91	81
144	97	87	86
172	110	104	89
142	107	121	107
176	131	115	106
171	115	117	99
178	116	95	86
203	111	106	106
186	108	103	110
187	108	101	100
150	114	115	90
182	96	98	100
177	94	86	106
168	103	90	113
187	92	110	115
189	96	99	108
164	113	102	107
151	97	104	101
120	106	112	110
138	102	98	99
126	103	112	93
100	74	90	95
119	103	115	90
104	90	99	82
120	80	109	73
98	81	117	74
125	90	120	58
127	91	135	66
114	90	132	69
125	86	123	58
95	116	145	110
132	111	132	118

Sketch Map I, 1931-32

Yield of grain in "tolas" of original 160 plots of one acre during the year 1931

113	115	79	131
73	106	72	79
75	112	83	51
66	98	74	54
74	84	75	39
65	75	100	45
83	69	80	41
65	84	88	41
70	88	87	62
70	93	86	78
89	106	78	72
80	110	86	84
105	100	84	84
88	78	71	72
77	92	77	80
90	75	74	55
87	72	73	68
95	77	68	48
90	24	65	50
70	59	57	59
73	67	57	52
65	64	53	57
70	68	58	50
65	62	71	37
75	62	56	40
70	55	81	41
88	62	105	27
49	54	79	33
71	64	80	22
77	69	95	20
64	66	80	14
59	77	72	14
65	68	41	9
62	72	85	7
72	60	65	14
60	67	77	13
98	67	61	7
85	68	54	8
84	59	36	5
90	62	49	4

Sketch Map I, 1932-33

Yield of grain in "tolas" of original 160 plots of one acre during the year 1932

96	133	136	128
97	110	104	115
93	82	128	128
70	108	121	133
71	99	133	138
97	108	102	145
90	111	128	171
81	112	124	120
96	122	137	150
96	110	118	127
108	104	162	107
97	127	164	64
104	112	176	119
121	142	143	153
159	134	170	123
163	151	155	113
163	132	127	98
136	141	135	118
174	125	116	98
150	160	124	73
176	131	164	74
185	146	91	97
253	132	132	93
153	125	110	90
197	154	103	106
205	143	121	107
160	178	117	109
158	165	133	111
176	160	83	116
164	155	119	84
147	157	129	108
155	132	125	82
165	128	144	102
103	127	140	92
152	144	122	98
151	141	138	75
186	155	122	53
119	130	130	68
133	137	115	60
161	139	118	51

PRELIMINARY OBSERVATIONS ON SMALL-LEAF DISEASE IN COTTON

BY

V. P. GOKHALE, B.Ag.,
Department of Agriculture, Bombay

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Introduction

A peculiar disease in cotton which manifests itself in the reduced size of leaves and sterility of the plant has since long been recorded in the Bombay Presidency. A few observations were made by Kottur and Patel [1920], but no attention appears to have been paid to this disease until 1933 when its incidence was reported to be as high as five to fifteen per cent in the Southern Maratha Country. In August of the same year, the Indian Central Cotton Committee provided funds, for a period of one year, for the survey of the disease in the Bombay Presidency including the Baroda State, but this work was not begun until very late in the season. Side by side with the survey work, preliminary experiments were made on the nature of the disease, but some of the experimental work was unfinished at the end of the year. The following report therefore is incomplete in some essential respects, but it has been considered worthwhile to record the observations made during the period of December 1933 to October 1934.

Distribution and extent of damage

A survey of the disease was undertaken in the important cotton-growing tracts of the Presidency, namely, Gujarat (including the Baroda State), the two districts of Khandesh and the Southern Maratha Country. In determining the amount of damage, an area of about four to five acres was selected at random in a village and the total number of plants in the whole area was calculated by multiplying the average number of plants in a line by the number of lines. The number of diseased plants was determined by actual count. From these figures the percentage of infection was calculated. However, when larger areas were selected for observation, the amount of damage was determined from the number of diseased plants in a few sections selected at random in the area. In addition, information on the following points was obtained whenever possible: (1) kind of soil, (2) variety of cotton, (3) rotation followed in the preceding years, (4) approximate date of sowing, and (5) insects found on diseased and healthy plants.

The incidence of the disease in each variety of cotton in the different tracts of the Presidency and in the Baroda State is summarised in Table I.

TABLE I

Amount of damage by Small-Leaf disease to different varieties of cotton

Variety of cotton	District	Percentage of diseased plants
	Southern Maratha Country	
Jaywant	Dharwar	0·1 —2·2
	Belgaum	0·24—2·3
	Bijapur	0·10—2·1
Kumpta	Dharwar	0·17—1·15
	Belgaum	0·10—1·70
	Bijapur	0·30—3·50
	Gujarat and Baroda	
Kanvi	Baroda	0·0 —1·18
	Mehsana	0·57—1·33
	Kaira	0·52—3·41
Desi cotton	Baroda	*Nil*
	Broach	0·05—0·5
	Surat	0·10
Rozi cotton	Kaira	*Nil*
Do. (1st ratoon)	Do.	8·75—13·94
Do. (2nd ratoon)	Do.	17·23—21·22 (even up to 33 per cent in some places)
B. D. 8	Surat	Less than 0·1
	Broach	0·0—0·2
Wagad local	Mehsana	4·88—6·74
	Ahmedabad	*Nil*
Wagad 8	Mehsana	0·40—9·39
Chokdio	Do.	0·55
Lalio	Do.	3·00
Broach 9	Baroda	0·10
1027 A. L. F.	Broach	Negligible
	Surat	Less than 0·1
	Khandesh	
Neglectum types	West Khandesh	*Nil*
	East Khandesh	*Nil*

It will be seen from the table that the disease is of widespread occurrence, but was not found in the southern part of the Surat district or in Khandesh. It was not severe in 1933-34, although its incidence ranged from five to fifteen per cent in the Southern Maratha Country in the previous year. Inquiries with the cultivators revealed that the disease varies in severity from year to year.

The survey in Gujarat was not undertaken until February 1934, when the cotton crop had been seriously affected by the severe frost, and it was difficult to recognise diseased from healthy plants in the field. In many places the picking of cotton was over when the fields were visited for observations, and it was further found on enquiry that cultivators in Gujarat uproot diseased plants as soon as they are noticed in the field and feed them to the cattle. The information on the amount of damage by the disease in Gujarat is therefore incomplete.

The survey work in Khandesh was begun in the middle of September 1934, and from the reports received till the close of the enquiry in October 1934, it was found that not a single diseased plant had been observed in the Neglectum types of cotton.

The following other points of interest are brought out by the table:

(*a*) The incidence of the disease varied from 0·2 to 3·5 per cent in the Southern Maratha Country and from 0 to 10 per cent in annual types of cotton in Gujarat, where the ratoon crop usually suffers damage up to about thirty-three per cent. In Khandesh the disease was not observed. On the whole the disease was much less in evidence in 1933-34 than in the previous year.

(*b*) In the Kaira district, where ratooning of cotton is normally practised, the disease appears in a virulent form in ratoons of Rozi cotton. The first year's crop is free from the disease, which appears in the ratoon crop to the extent of ten to fifteen per cent, and is greatly intensified in the second ratoon, the damage varying from eighteen to thirty-five per cent.

(*c*) Foreign varieties and the Neglectum types of indigenous cottons were found to be free from the disease. All Herbaceum types were affected.

(*d*) There was no evidence that any variety of Herbaceum cotton was more resistant to the disease than another.

On the Dharwar Farm, observations were made on the appearance of the disease in cotton in an area of 1½ acres. Of the total number of diseased plants observed from November 1933 to February 1934, thirty-six per cent were noticed in November, 42·8 per cent in December, seventeen per cent in January and four per cent in February. The disease continued to appear even after February, but late attack did not affect the yield as the bolls were fully opened by that time.

No survey was made in the Ahmedabad and Panchmahal districts, and in the Navasari district of Baroda State.

Symptoms of disease

Before the appearance of the disease, the leaves on all plants are alike in colour and size, and no distinction can be made between a diseased and a healthy plant. About twelve to thirteen weeks after sowing (or sixteen weeks in the late-sown crop), a plant here and a plant there in a field may be seen putting forth numerous small leaves in clusters, and the dormant buds on the main stem as well as the axillary buds are stimulated to activity, thus indicating distinct departures from normal growth. The leaves on diseased plants are considerably reduced in size and measure from 0·3 to 2·3 cm. in length and 0·5 to 3 cm. in breadth, whilst those on healthy plants measure from 1·4 to 3·4 cm. in length and 1·5 to 4·1 cm. in breadth. The colour of diseased plants gradually changes to pale green, and old leaves on such plants, though of normal size, turn red along the margins on the upper or the lower surface. The reddening continues in the tissue between the veins, and such leaves wither and drop down in about tree weeks. On the small leaves', however, small black specks appear, but these leaves may or may not turn red along the margins. The diseased plants give the appearance of a "witches broom". No mottling of the leaves has been observed, although curling is present to some extent.

The petioles are reduced proportionately in size. The bracteoles attain a good size, and persist on the plant for a long time, but the bud inside the bracteoles becomes flat and suppressed and withers in a few days. Over the suppressed bud the calyx forms a cup-like organ. The petals are changed into small, thick, leafy structures, and other floral organs are extremely reduced in size. Such plants remain sterile.

An affected plant has never been seen to recover, and after the appearance of the disease its rate of growth is much slower than that of a healthy plant. The diseased plants wither within the course of two to three months. Many plants are partially affected, the healthy part producing normal bolls. If a plant is affected after the bolls are formed, the bolls do not make much further growth but are cracked and open out early. The disease may originate in any part of the field and not necessarily along the borders. There is no marked difference between the root systems of the diseased and healthy plants. It is not usual to find all the plants in a hill showing the disease.

Nature of the disease

That the disease is not parasitic in nature has been proved by repeated isolations from the affected plants. There is also no evidence that atmospheric or soil conditions cause the disease. Analyses of soil samples from around the diseased and healthy plants have shown no difference in their chemical composition, nor has the application of farmyard manure in varying quantities to different plots pre-disposed the plants to infection.

None of the cotton plants inoculated with the juice of diseased plants showed symptoms of Small-Leaf disease. Also, all attempts to transmit the disease by means of insects from naturally infected cotton plants to healthy plants in muslin cages gave negative results. The result of the transmission of the disease by grafting were inconclusive, since these experiments failed due to graft union not being successful. There was no opportunity to repeat these experiments.

Study of the disease in the ratoon crop

Field observations indicate that ratoon cotton suffers badly from the disease. The following is the brief summary of the observations made at different places.

Surat Farm.—Five hundred and seventy-six healthy plants of 1027 A.L.F. were cut back in May 1934. About the end of September, 1·2 per cent of these plants showed definite symptoms of Small-Leaf disease.

Broach Farm.—Two hundred and fifty-four healthy plants of B.D.8 cotton were ratooned and 1·2 per cent of these were infected.

Lambhvel and Bhumel (Kaira district).—No disease was observed in Rozi cotton in the first year. In the second year crop, *i.e.*, the first ratoon, 3·26 per cent plants were diseased out of 675 plants examined; whilst in the second ratoon that attack was greatly intensified, about 35·7 per cent of 1,120 plants examined showing infection.

Village Jamania in the Surat district.—An area of about seven acres under 1027 A.L.F. was examined, but only one diseased plant was observed, although cotton is commonly grown as a ratoon crop in this tract. It appears that the ratoon crop of Rozi cotton in the Kaira district is more liable to disease than 1027 A.L.F.

Dharwar Farm.—After uprooting all diseased plants, the apparently healthy plants were cut back on the 12th June 1934, leaving about six inches of stem above-ground. Most of the plants sprouted as there was good rain in the month of June. Whilst many plants put forth normal leaves and branches, the leaves on some of them were very small, irregular in shape and much crowded near the sprouting buds; the latter plants did not make much growth but for want of definite symptoms, they could not, however, be classified as diseased. About two months after sprouting, the leaves on these suspected plants began to wither, and by the middle of September, twenty-four out of 303 plants under observation showed definite symptoms of Small-Leaf disease. Of these twenty-four plants, four were stunted in growth from the beginning, and the remaining twenty plants became infected later in the season. Unfortunately, however, both the healthy and diseased plants withered due to lack of rains, and no further observations could be made.

Gadag Farm.—The cotton plants were cut back on the 25th May 1934. Out of 378 plants, 257 plants sprouted, but all withered due to lack of rains.

CONCLUSIONS

It may be noted that, besides ascertaining the extent and the amount of damage caused by the disease, one object of the survey was to accumulate preliminary evidence relating to the nature of the disease. The information collected during the year, though of a preliminary nature, points to the disease being a teratological malformation.

Summary

The disease is of widespread occurrence and affects varieties of cotton of the Herbaceum type; none of the Neglectum types has been found to be infected. The disease does not attack foreign varieties of cotton.

The disease was much less in evidence during the year under report. The severity of attack varies from year to year.

In the Kaira district the disease is serious in the first and second ratoons, although the crop in the first year is free from it. The damage to the second ratoon may be as high as thirty-five per cent.

The symptoms of the disease have been described. The important symptom is the reduced size of the leaves which appear in clusters. The affected plants are sterile, and the floral organs show teratological malformations.

No evidence has been obtained that parasitic organisms are associated with the diseased plants; nor does the disease appear to be caused by insects or by soil or climatic conditions. The disease was not transmitted to healthy plants by insects taken from naturally infected plants nor by the juice expressed from the diseased plants. Experiments on the transmission of the disease by grafting were inconclusive.

Observations on the disease in ratoon cotton at various places have been summarised. It appears that the Rozi cotton is more liable to disease as a ratoon crop.

The writer is grateful to the Indian Central Cotton Committee for the provision of funds which enabled him to do this work.

REFERENCE

Kottur, G. L. and Patel, M. L. (1920). *Agric. J. Ind.* **15**, 640-643.

INHERITANCE OF CHARACTERS IN SORGHUM—THE GREAT MILLET

VIII.—A BROWNISH PURPLE MUTANT

BY

G. N. RANGASWAMI AYYANGAR, B.A., I.A.S.,

Millets Specialist, Agricultural Research Institute,

AND

A. KUNHIKORAN NAMBIAR, B.Sc. Ag.,

Assistant, Millets Breeding Station, Coimbatore

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(With Plate XXXII)

The prominent vegetative part of the sorghum plant is usually devoid of marked purple pigmentation. In red-grained varieties there is a reddish sap colour that appears mostly at the margins of the leaf, when it begins to dry up. Apart from this colour, sorghum does not show much distinguishing purple pigment in the vegetative parts. Such colour differences as there are seen only in the grains and in the dry anthers. Ther eis thus an absence of noticeable purple pigmentation in the vegetative parts. This pigmentation is however potential and is activated on mechanical injury. This pigment is anthocyanic and does not colour the mechanical tissue.

Since the inception of the intensive study of sorghums in Madras in 1923, millions of individual plants from many varieties have been marshalled for examination and till the year 1931 no instances have been met with of a plant with internodes brownish purple and the midribs coloured likewise. This brownish purple was not anthocyanic, and seems to be somewhat similar to the brown of the brown midrib in maize. [Jorgenson, 1931, and Burnham and Brink, 1932].

In the variety of *Periamanjal cholam*, the prominent grain sorghum variety of Coimbatore, intensive selection work has been in progress for a number of years. Among the selections of this variety, which is green-stemmed and whose leaves have a white midrib, there occurred in 1931, a brownish purple mutant. This mutant, while being very slightly shorter and weaker, was in general configuration like the rest of the population, only it had brownish purple-lined internodes and leaf-sheaths, and brownish purple midribs in the leaves. The internode colour was present even on the portions of the internode covered by the leaf-sheath. This plant bred true. Crosses between this mutant and a plant of the mother population showed that the colourless internode and midrib were dominant, setting down this brownish purple mutant as a definite recessive. The second generation plants gave the following segregations.

Family No.	F_2 segregating for	
	Green internode and leaf-sheath, white midrib, etc.	Brownish purple lined internode, leaf-sheath, midrib, etc.
A. S. 3636	121	37
,, 3645	127	41
Total (observed) . .	248	78
,, (calculated) .	245	81

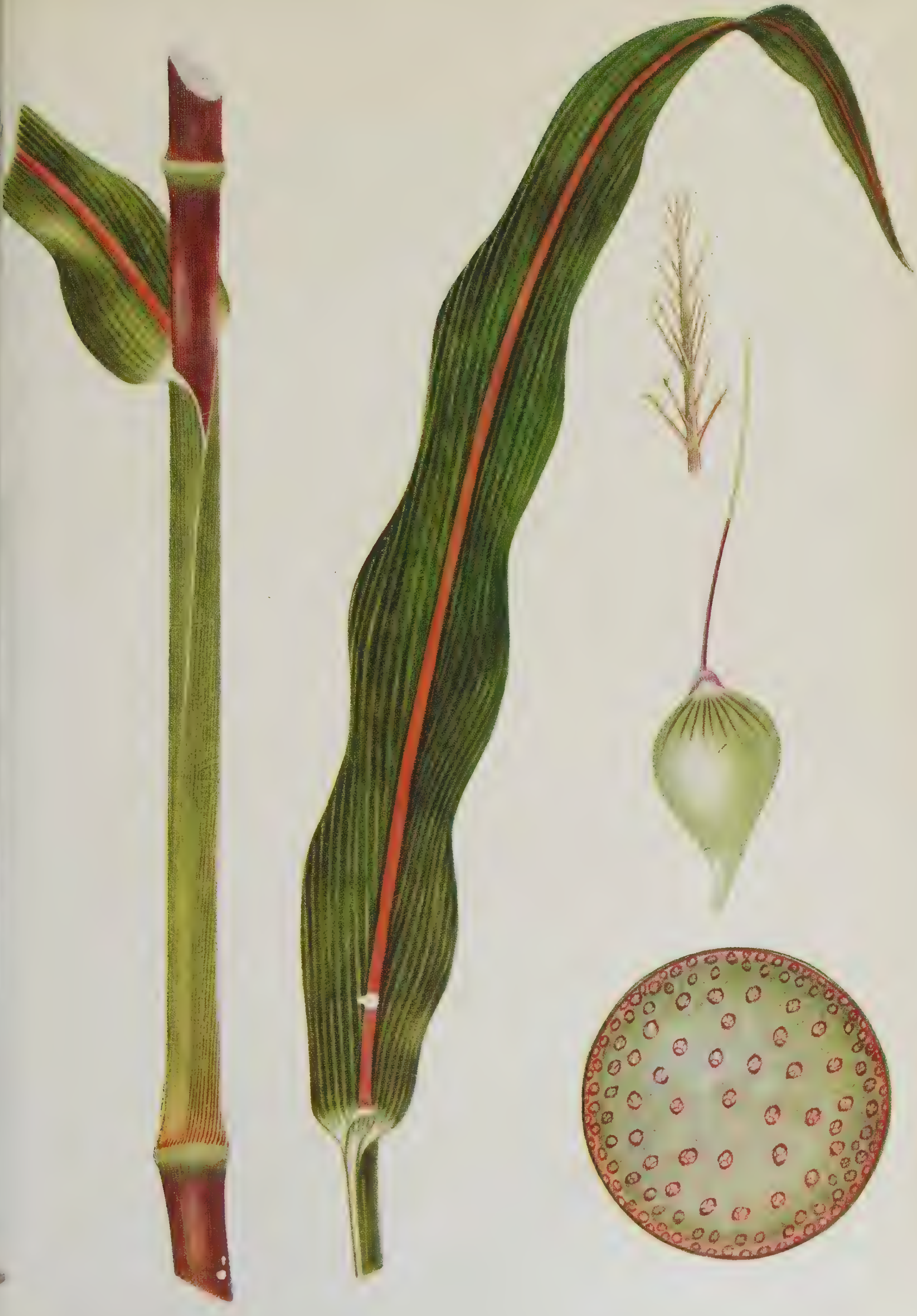
$\chi^2 = 0 \cdot 15$, $P > 0 \cdot 5$

It will be seen that the segregation is monofactorial and that the mutant has proved a simple recessive.

Sections of the stem, exposed roots and panicle branches show that the pigment colours the mechanical tissue of the plant (Plate XXXII). It may be noted that the coloured stems were a bit harder to section.

The first traces of this brownish purple pigmentation are noticed when the seedlings are even a week old. The midrib is the earliest to develop the colour. The upper surface of the midrib is coloured brownish purple, while the lower surface is more deeply coloured, with an accentuation towards the ridge of the midrib. The intensity of colour in the midrib increases with the growth of the seedlings, and in about thirty to forty days after sowing the leaf-sheath also begins to manifest the pigmentation in lines. In due course the other parts of the plant, *viz.*, internode, panicle branches, glumes and even the exposed roots develop the colour. It is during the milky stage of the head that the deepest manifestation is noticed and at this period the stem, exposed roots and glume nerves are of a good brownish purple colour. After the milky stage there is a gradual falling-off of the colour, first in the midrib, then in the leaf-sheath, panicle branches and glume nerves. In the midrib a faint brownish purple over a yellowish background is retained to the last. The colour in the internode remains even after harvest, but gradually fades into a pale brownish purple tint in the stripped dry stalks.

PLATE XXXII.



Colouring effect of pigment on the mechanical tissue of the plant.

The non-existence of this brownish purple type in current varieties and this rare occurrence as a recessive mutant connoted probable disabilities. Over 300 plants in each of green and brownish purple internodes were examined and the following notes recorded:—

	Green	Brownish purple
Average height of plant	320 cm.	270 cm.
Average weight of earhead	80 grms.	70 grms.
Average weight of straw	330 grms.	250 grms.

In segregating families this difference tended to be kept up, the disabilities of the brownish purple going with it. The brownish purple plants were more juicy than the green ones at about the milky stage. Later on they dried up more rapidly than the greens and left lighter stalks.

Sorghum varieties vary in their juiciness, height, weight of earheads and other economic characters. The particular disabilities of this brownish purple mutant are therefore by themselves not likely to have been the deciding factors in the rarity of their occurrence. This mutation in sorghum may therefore be an echo of an ancestral equipment. Inhibitory factors with favourable physiologic reactions have probably operated to suppress this pigmentation and create the wide group of grain sorghums devoid of brownish pigmentation in their mechanical tissues. A factor **mt**$_b$ gives a mechanical tissue coloured brownish purple. **Mt**$_B$ gives the ordinary green internode of the common sorghums.

SUMMARY

The occurrence, as a mutant, of a sorghum plant with brownish purple-lined internode, leaf-sheath, midrib, panicle branch, and glume top is recorded. The pigment is not anthocyanic. This mutant behaves as a simple recessive to the common more economic green-internoded and white-midribbed plant. A factor **mt**$_b$ gives a mechanical tissue coloured brownish purple. Mt$_B$. gives the ordinary green internode of the common sorghum.

REFERENCES

Burnham, C. R. and Bink, R. A. (1932). *J. Amer. Soc. Agron.* 24, 960-963

Jorgenson, L. R. (1931). *J. Amer. Soc. Agron.* 23, 549-57.

BANANA BREEDING AT THE IMPERIAL COLLEGE OF TROPICAL AGRICULTURE, TRINIDAD

(With a view to obtain a type resistent to the Panama disease, includin genetical and cytological studies on allied species)

(*Summary of work done by Prof.* E. E. CHEESMAN *and Mr.* L. N. H. LARTER, *as reported in the Empire Marketing Board's Report of December, 1931, and Journal of Genetics, Vol. 26, No. 3, December, 1932, and Vol. 30, No. 1, January, 1935*)

BY

G. S. CHEEMA, D.Sc., I.A.S.,

Horticulturist to Government, Bombay, Poona,

AND

S. S. BHAT, M. AG.,

Horticulturist, Baroda State, Baroda.

Professor E. E. Cheesman of the Imperial College of Tropical Agriculture, Trinidad, has carried out very valuable work in the production of a new variety of banana, combining resistance to Panama disease with the good commercial qualities of Gros Michel, the present outstanding variety of northern markets. The following lines are a summary of work done by him, and the results obtained upto the year 1935.

The importance of banana as a dessert fruit is emphasised by Dr. T. Drummond Shiels [1931], Chairman of the Research Grants Committee of the Empire Marketing Board, in the following words: "Fruit is steadily becoming more popular in the United Kingdom, and the banana is fully sharing in this very welcome trend of public taste. A record for the consumption of bananas was set up in 1930 by an import figure of almost 15,000,000 bunches. Nearly 6,000,000 of these came from the West Indies, whose exports of bananas to the Home market have increased very rapidly in the last five years. The banana industry, therefore, is important both to this country which is concerned with securing an ample supply of good fruit from Empire sources, and to parts of the West Indies, which are depending more and more on the crop for their living".

The work detailed here is considered to be of immense value to the banana growers of India also. The importance of the banana crop to this country may be easily gauged from the fact that the Presidencies of Madras and Bombay alone grow 144,000 and 21,556 acres of banana, respectively, with a very wide field for further extension. At the same time, the Panama disease has been recorded in several places in this country, and many flourishing plantations are seen to be devastated by it within a very short period. The account of work done at Trinidad, therefore, will be found highly valuable to the Indian growers and fruit merchants at this juncture.

This summary is divided into three sections, the first dealing with the Breeding Work. The second and third sections deal with cytological studies of bananas and allied species carried out with a view to elucidate their breeding behaviour. Incidentally, the cytological work has thrown considerable light on the internal classification of the Sub-order, *Musaceae*.

Section I

BANANA BREEDING AT THE IMPERIAL COLLEGE OF TROPICAL AGRICULTURE, TRINIDAD [CHEESMAN; 1931, 1].

At the Imperial College of Tropical Agriculture, Trinidad, the banana breeding work has been in progress since 1922. The Gros Michel banana combines a variety of commercially desirable characters, but it is highly susceptible to the Panama disease. Several other varieties possess the character of being immune to the Panama disease, but they lack in commercial qualities. The "building in" together of these two sets of characters by breeding has presented a good deal of difficulty in view of the facts:—

(1) that the commercial banana is ordinarily a sterile type producing no seeds,

(2) that it is essential to induce seeds in it for any breeding work to be possible at all,

and (3) that the seed-bearing character should be finally eliminated in any new type, which may be evolved, before it can be commercially unblemished and popular.

The difficulty is further accentuated by the fact that the bananas of the world have not been properly studied and classified, and the present knowledge about them is imperfect.

PREVIOUS INVESTIGATIONS

The work done by Tischler [1910], D'Angremond [1912, 1914], White [1928] and others has shown that the pollen formation in some varieties like Dole (8 chromosomes) is regular, while it is very irregular in others like Pisang Klady (16 chromosomes), Radjah Siam (24 chromosomes), etc., the irregularity apparently increasing with the increased number of chromosomes. Tischler [1912] found that the development of embryo-sac was normal in fertile and abnormal in sterile types of bananas. He recorded that in Java certain edible types of bananas often produced seeds. D'Angremond obtained a few seeds in Gros Michel and Appelbacove varieties, and found pollen development in Gros Michel as highly irregular. The fertile varieties he studied were more regular in this respect. The work of Palm [1920] suggests similar behaviour in other plants belonging to *Musaceae* and *Zingiberaceae*, indicating that this type of irregularity exists in the whole order of *Scitamineae*.

White [1928], who chiefly used root tips for his cytological studies of bananas, observed an excellent polyploid series in about 150 varieties of *Musa*, and held that the basic haploid number of chromosomes in bananas is 4. White further recorded that the series is not quite euploid, counts of 18, 22, 23 chromosomes also having been obtained.

The F_1 generation produced from a cross made by D'Angremond [1926] between two fertile species showed that the reduction of chromosomes is very irregular and that the hybrid produced little fertile pollen. He observed that increased pollen fertility was a feature of the back-cross progeny, no individual of which exhibited parthenocarpy.

Details of investigations

The banana breeding work at Trinidad was the result of the initiative taken by the Colonial Research Committee, who were alarmed by the spread of the Panama disease in Central America. Sir Francis Watts, then the Imperial Commissioner, proposed an extensive collection and study of banana varieties at a central station, as in the case of sugarcane, in order to combine the commercial qualities of Gros Michel with resistance to Panama disease. In the year 1922, the Imperial College of Tropical Agriculture was founded at Trinidad, and this work was started there with the financial aid of the Colonial Office.

Facilities were offered by the Trinidad Department of Agriculture to work upon six varieties of bananas to start with at the St. Augustine Experiment Station. Dr. T. G. Mason and Professor J. S. Dash worked successively in the earlier stages of this research, and began investigations with a very large-scale pollination experiment. Several edible varieties of bananas were intercrossed, as well as crossed with fertile pollen of seed-bearing types, namely *Musa ornata*, and *Musa malaccensis*.

Before proceeding further, it would be proper here to describe the main characters of the two parental types of bananas, Gros Michel (female parent) and *Musa malaccensis* (male parent), which have played important roles in these investigations.

The Gros Michel is a well-known commercial variety of banana from West Indies, tall and vigorously growing in habit. The fruit bunch hangs vertically downwards, and is very compact fulfilling commercial requirements. The fruit is about six inches long and tapers towards the end. When ripe, all the angles on the fruit get rounded, and a bright golden yellow colour is developed. This variety is, however, highly susceptible to the Panama disease. Owing to its popularity, commercial importance and breeding potentialities, it will be noticed in the following account that much attention has been devoted to it.

The seeded variety from which pollen were obtained to cross on Gros Michel was *Musa malaccensis*, the origin of which is not definitely known. It seems to be a variety of *M. malaccensis* Ridl., which latter is itself according to Backer, a variety of *Musa zebrina* Van Houtte. Several authors consider *M. zebrina* and *M. malaccensis* as synonyms, and the former name, having the advantage of priority, should be adopted. The plant is similar in habit as edible bananas, except that it is less vigorous in growth. The fruit bunch is irregular and is held at an angle above the horizontal. The fruit is about three inches long, round and has a pronounced beak. The ripe fruit has a golden yellow colour. Seeds are abundant. No case of parthenocarpy is yet observed in the fertile species of Musa.

As a result of cross-pollination, forty-nine perfect seeds in Gross Michel, and seventy-four in Silk, were obtained with pollens of the seeded types, except one seed which was obtained from a cross of Gros Michel by the edible type Congo. Of the Gros Michel lot, seventeen seeds germinated and only five seedlings survived to fruit.

Side by side with breeding work, botanical and mycological studies and tests of resistance of varieties were also carried on separately by Professor Dash and Professor Ashby. Dr. S. C. Harland and Mr. Cheesman took over the breeding work in 1923.

In March, 1925, one of the Gros Michel hybrid seedlings flowered and produced a fair-sized seedless fruit of good flavour. This seedling was then labelled GM×B2. This plant resisted Panama disease during six years of severe test, and was re-named I. C. 1 (Imperial College 1). It had, however, some commercial disadvantages, and an occasional seed appeared in its fruit as a result of self-pollination, when it was propagated by suckers, and grown under ordinary banana field conditions. Further work was continued to improve upon I.C.1. Cytological studies of the hybrids and their parents were also commenced at this stage, and extensive pollinations were made on a number of varieties. I. C. 1 was further multiplied and back-crossed to each of its parents.

As a result of Dr. Harland's visit in 1925, to several Tropical countries of the world, many new types of banana have been introduced into Trinidad to work upon.

After several unpromising attempts with other varieties of bananas, crossing and back-crossing on Gros Michel were resumed in 1927, and continued since then. Back-crossing of I. C. 1 on Gross Michel was for some time concentrated upon as promising a type, more akin to Gros Michel but quite resistent to Panama Disease. But these two types proved to be cross-sterile. Cytological studies, however, revealed that the I.C.1 seedling possesses a double complement of Gros Michel chromosomes, and as the results of back-crossing were considered uncertain, I.C.1 was left as it is. The breeding problem was tackled from other sides of attack.

Since it is held that the present edible types of bananas must have originated from wild seed-bearing types, a general survey of the genus *Musa* was considered valuable in this work. Examination of the recorded systematic knowledge of *Musa* was, therefore, taken up. It was found that 134 specific names must have been listed under *Musa.* A much larger number of varietal names were found under *Musa sapientum.* The numerous languages and dialects of the world seemed to increase the number of banana varieties almost indefinitely, although many of them may be identical types. It was, therefore, considered necessary to ignore a large section which was useless for the problem in hand, and basing the studies on the *Eumusa* and *Rhodochlamys* groups, twenty seeded types and forty edible cultivated types have been collected at the Imperial College of Tropical Agriculture, Trinidad. In the elimination of identical types, rigid tests, including cool storage qualities were adopted. By this method of comparison and elimination, nearly a hundred original types are now reduced to less than thirty "Standard types" for basing future work upon.

The technique of introducing these varieties has been necessarily elaborate, in order to minimise the import of new diseases to the central place of collection along with suckers of the varieties. All introductions were certified as healthy in countries of origin, then first taken to Kew, where a special quarantine was built for this purpose. When they produced new suckers, which were considered healthy under the Kew quarantine conditions, the suckers were sent to Trinidad, where again they were further tested in an insect-proof greenhouse, before planting in the open varietal plot. This course was essential in the case of sterile varieties, which had to be introduced by means of vegetative suckers. In the case of seeded varieties, the question was much simpler, although seeds had to be obtained with considerable difficulty and risk from unexplored wild regions.

The details of actual breeding work carried on at Trinidad can best be summarised under three headings, namely,

(1) breeding from Gros Michel,
(2) breeding from other edible varieties,
and (3) breeding from seeded types alone.

General summary of breeding work

Technique.—The technique of the operations in the breeding work consisted of bagging inflorescences of both the male and female parents with calico bags before the bracts lifted in order to keep up their purity. Pollination was done daily in the morning on inflorescences which had just opened. A scalpel or camel hair brush, duly sterilised in alcohol after every change of pollen, was used for transferring pollen. Labelling was carefully done in each case, giving all necessary details such as pollen used, date of pollinating, etc. The bunches which formed were harvested when fully developed, and collected in a separate room for searching seeds in their fruits. Seeds of edible varieties were carefully sown individually in pots, and seedlings were, after proper hardening, transferred to the nursery. Only suckers from nursery stools were planted out in the field for further observations keeping back enough material for cases of emergency.

Sterility in bananas.—Sterility in bananas is manifested in their poor seed-producing capacity as well as in the low germination of seeds. Seeds are often produced without endosperm. Even after germination, abnormal growth or lack of vigour results in premature death of the seedlings. From 1,000 inflorescences pollinated, hardly 474 seeds were produced, of which only 42 germinated.

Breeding from Gros Michel

Breeding from Gros Michel is being explored in every direction, as its potentialities are vast. The I.C.1 seedling is not yet considered the best that could be obtained. In crossing Gros Michel, both edible varieties which produce fairly abundant pollen, as well as fully fertile species are used as male parents. As stated above, Gros Michel and I.C.1 presented cross-sterility. The pollen of Gros Michel itself is also being used on other seeded types. A second immune seedling I.C.2 from Gros Michel crossing was also used for taking pollen but it gave no result.

Attempt is made to produce the F_2 generation of the I.C.1 type both by artificial and natural pollination, and nineteen seeds thus produced have yielded three seedlings for further study. Back-crossing of I.C.1 on its male parent resulted in abundant seeds, but not in a single economically useful seedling.

Breeding from edible varieties other than Gros Michel

In breeding from Gross Michel, attempt was made to combine disease resistance with its good characters. But in breeding from other edible types, which show resistance to Panama disease, the difficulty is accentuated by their undesirable commercial characters. Such characters would be required to be eliminated. From the breeder's point of view, however, the preliminary questions would be to find out the seed-producing capabilities and the kinds of offsprings each type might give. Work was commenced with a view to solve these two points on Cavendish, Congo, Sapientum, and Fillbasket group of bananas.

Plants of *Musa cavendishii*, known as the Cavendish, Canery or Chinese banana, have been introduced from various parts of the world to study the variability within its sub-groups. The fruit of this type is of high quality. The chances of breeding from this group seem to be slender. No seeds are yet obtained although several attempts at crossing were made.

The Congo group includes five varieties of dwarf plants. They are very similar to Gros Michel, being marked off from it by their resistance to Panama disease, cold storage qualities and breeding behaviour. Over 140 attempts to cross this group with several other seeded and unseeded types resulted in a single seed being obtained.

Musa sapientum includes a great variety of edible bananas. They are in general of poor dessert quality. The pathology of this group is not exhaustively studied, but some of them seem to be resistant to Panama disease. These varieties are studied chiefly for genetic information, and their behaviour is interesting. They produce a large number of seeds, most of the seeds being empty. Seedlings from a cross with a member of this group proved to be intermediate between the parents, showing no doubling of chromosomes from the female parent as in the case of Gros Michel.

The Fillbasket group includes the Mysore type and has a few characters, which recall *sapientum*. The Fillbasket has resistance to Panama disease and wind damage; it has a vigorous habit with neat and compact bunch, good fruit colour, and fairly abundant seeds on pollination. But the fruits are small and thin-skinned. Out of fourteen germinations obtained from about 200 seeds got by crossing this group, eight robust plants of promise are growing in the nursery at the Imperial College (1932).

Pollinations on miscellaneous edible varieties have brought out the facts that—

(1) generally seeds are more common in red varieties,
(2) a yellow-fruited variety may often arise from red types,
(3) Coccenia (not related with *M. coccenia* Andr.) is a seed-producing resistant banana with promise.

A few pollinations on plantains have yielded two seeds, plants from which were studied.

Breeding from seeded types alone

A large number of seedlings with "intermediate" characters were obtained by breeding from seeded types alone. These types also are generally self-sterile. Back-crosses on the parents of the hybrids are more successful and are seen to produce uniform progeny suggesting that the chromosome complements go over without reduction. D'Angremond's [1926] trials, supported by the Imperial College results, show the possibility of evolving edible bananas which usually have a chromosome number of 33, from seeded types which have 22 chromosomes, by raising species-crosses having 33 chromosomes. The great requirement is to find the proper parent species for this end, and an enormous amount of work will have to be done by making hundreds of crosses and back-crosses in future.

Section II

GENETICAL AND CYTOLOGICAL STUDIES OF MUSA

1. *Certain hybrids of the Gros Michel banana* [Cheesman, 1932]

In the efforts to evolve a disease-resistant and commercially unblemished type of bananas, cytological study of banana varieties was considered very important to elucidate the breeding behaviour in the parthenocarpic forms.

Professor Cheesman's [1932] investigations detailed here do not support White's [1928] theory that the basic haploid chromosome number of the banana complex is 4 (*vide* page 486), and that the common condition in edible bananas is octoploid, but they indicate that the basic haploid number is 11, and the common condition is triploid.

Professor Cheesman's cytological investigations [1932] have been confined to somatic divisions and meiotic divisions in pollen mother-cells. The terminal bud of banana inflorescence, after it has passed the "female" (or fruit-bearing) stage, was cut and removed at once to the laboratory. The bracts with the "hands" of flowers were dissected and kept separately. The likely flower was crushed in a drop of water, and examined under a low power microscope for the condition of the pollen grains. Flowers at the stage when they could be examined measured about one cm. long and two mm. in diameter. They presented no difficulty in fixing. Root tips for examination were also readily obtained from rhizomes kept in a moist atmosphere in the dark, or planted in sand. The time between 5 and 6 o'clock in the evening was found best to fix the material. Desirable stages were almost invariably found at this time, although several fixations were necessary, before satisfactory preparations could be obtained. The most satisfactory fixative was found to be Tellyesnicky's Bichromate acetic acid mixture (six per cent potassium bichromate and ten per cent acetic acid). After washing the material was treated by a modification of Larbaud's [1921] method, and sections were cut at 5 μ and 10 μ and stained in Newton's Gentian violet. Euparal was preferred for mounting.

Cytological studies of Gros Michel, the female parent of I. C. 1

D'Angremond [1912, 1914] and White [1928] studied the cytology of Gros Michel and they both agree that its diploid chromosome number is 32. But the number found by Cheesman [1932] based on counts made at the first meiotic division and in root tips is 33.

In D'Angremond's [1912, 1914] studies, the chromatic substance of the nucleus was in the form of larger and smaller grains mostly lining the periphery. He never found a typical diakinesis stage and found the anaphase with the chromosomes straggling on the spindle.

White [1928], also found the chromatic material near the periphery, and he describes them as definitely 32, and in many cases pairing. He states that diakinesis is rather brief, and at this stage, he holds, that there are eight unpaired chromosomes and twelve pairs. At anaphase stage, White states that twelve chromosomes pass early to the poles, while eight lag near the equator showing a longitudinal split.

Cheesman's [1932] studies of Gros Michel show that the earliest stages show a loosening synizetic knot having threads of the bead string structure. Usually several round chromatic bodies and the nucleolus are present. In the next stage, long loops, characteristic of diplotene, are formed and the conjugation is more than simple pairing.

Diakinesis was observed in several cases, but it was difficult to fix this stage. The threads break into round granules connected in rows, and the chromosomes were actually shortening and thickening as usual.

The metaphase stage has various associations of which trivalents are more common. Two-thirds of the complements seem to be more commonly grouped than the remaining one-third. A very crowded and narrow equatorial plate is also formed in due course. Occasionally chromosomes are seen widely scattered, and perhaps in such cases the plate is omitted. In the typical anaphase stage, it is seen, that eleven chromosomes aggregate towards each pole, leaving eleven lagging of which several show signs of dividing.

After division I, the wall or walls rarely separate simple nuclei. Lagging chromosomes either remain isolated, or join several together to form secondary nuclear bodies. An irregular second division follows, and walls then form in every direction. This gives rise to multicellular "tetrads".

The number of pollen grains is small, their size variable and they are mostly empty.

Cytological studies of Musa malaccensis, *the male parent of I. C. 1*

The type "Seeded B", as *Musa malaccensis* was labelled at the Imperial College collection, showed no indication of segregation or abnormality of any kind when tested for its genotype. This type has 22 somatic chromosomes. Meiosis in the pollen mother-cell is not completely regular, one or two pairs of chromosomes lagging on the spindle. At metaphase of the first division, the chromosomes form a compact plate, and lend to counting only as they separate. The actual type of association seems to be five bivalents and three quadrivalents, or six bivalents grouping into three pairs, and five remaining more widely spaced.

The association persists into late anaphase, when the chromosomes show the split of the approaching second division, and reappears at the homotype metaphase. The tetrads regularly consist of four cells (very rarely five cells), but vary in their arrangements. The pollen is highly uniform in size, and about 100 μ in diameter. It germinates and grows well on one per cent agar with thirty per cent cane sugar, and 0·02 per cent citric acid. The percentage of germination in culture has not exceeded fifty. Seeds also have low germination power. These facts do indicate a certain degree of sterility in the seeded types of bananas also.

Cytological studies of the F^1generation, I. C. 1

The four original hybrids in the F_1 generation closely resembled the female parent, Gros Michel, and were alike among themselves except that physiologically I. C. 1 alone was resistant to the Panama disease. The bunch of I. C. 1 differs from Gros Michel in hanging slightly less vertically and being less compact. The fruit is rounded at the apex. The size and colour of the fruit, thickness of skin, terminal bud and male flowers are closely similar to those of Gros Michel. The male flowers of I. C. 1, however, produce abundant fertile pollen, but the production of seeds is scanty. Fruits develop parthenocarpically, and are edible and of good flavour.

The somatic chromosome number of I. C. 1 is 44, and on the assumption that this represents thirty-three from the female parent *plus* a haploid set from the male, the close morphological resemblance of Gros Michel becomes evident. The meiotic divisions are slightly more regular than those of Gros Michel, but the spindles are more compact and crowded. The chromosomes at metaphase of the first division are grouped into some associations of high valency which are difficult to analyse.

At anaphase, often both lagging and scattered chromosomes occur. Types of "dyads" are commonly met with during the second division. Lagging chromosomes are cut off in wedge-shaped cells, while scattered ones are distally severed. A proportion have only one cell surviving while the rest are disorganised. The whole set occasionally undergoes necrosis.

As in Gros Michel, multicellular "tetrads" are formed. Ripe pollen grains are irregular in size, though more abundant. Viable pollen grains carry 22 chromosomes.

The sister plants of I. C. 1 also gave similar results so far as they were examined. Among F_1 plants produced from later pollinations, two have entirely differed from I. C. 1, suggesting chromosome incompatibility by their very appearance. One of these plants was very dwarf, but both of them showed 75 chromosomes. Counts varied from cell to cell, and it may be that the true count is 77 (which is a multiple of the original basic haploid 11).

Cytological studies of the F generation

In the F_2 generation, I. C. 1 exhibits a high degree of self-incompatibility, although it has abundant pollen and seeds fairly well with pollen of *Musa malaccensis*. Fifty-seven inflorescences produced twelve seeds of which only two germinated, when pollinated by hand. Left to natural pollination 119 bunches produced but nineteen seeds, of which only three germinated. The vegetative habit of all of these is similar to I. C. 1. In three cases, however, the somatic chromosomes were 44, while in the other two they were 46. A giant cell in mitosis gave 92 chromosomes.

Back-crosses on Gros Michel

Pollen of I. C. 1 used on the female parent, Gros Michel, set even less seed than I. C. 1 itself. The relative compatibilities of the original parents and the hybrid were as shown below, when pollinations were tried under similar conditions:

Cross	Inflorescences	Seeds set	Germination
Gros Michel × *M. malaccensis* .	35	35	10
Gros Michel × I.C.1 . . .	24	1	0
I. C. 1 × I.C.1	57	12	1

The back-cross seedling was very slow in growth and attained a height of six feet only at two years of age, when it flowered. The bunch and fruits exhibited characters of the male parent, though the fruits were parthenocarpically developed and seedless. The male flowers were few, irregular and quite sterile.

The pollen mother-cells from the terminal (male) bud, were remarkably irregular in shape, varying from oval to abnormally elongated. Occasionally two or more cells are closely joined, though at a late stage of development. The nucleus is often at one end or on one side. The anaphase figures are most abundant and chromosomes straggle very loosely on the spindle. Chromosome counts gave 37 and 42, with 39 as the likely truth. At the first division one cell wall is usual, and highly irregular multicellular "tetrads" result in the second division as in Gros Michel. This plant was evidently an extremely unbalanced form.

Back-crosses on the male parent, M. malaccensis

Pollinations made on the male parent with pollen from I. C. 1 and a sister hybrid, GM × B61, set seeds which germinated freely. When these seedlings fruited, the two families resembled one another very closely. The second family, therefore, considered unnecessary and hence destroyed. Reciprocal matings between I. C. 1 and *M. malaccensis* produced no difference in the progeny.

The whole progeny proved heterogeneous, though varying from one another in minor details only. In vegetative habits, they mostly resembled Gros Michel, but the fruit bunch was intermediate between the two parents in its size and position. All were parthenocarpic and set seeds occasionally in some cases. The shape of the fruit and of the terminal bud varied most. Segregation on any simple numerical basis was not observed.

The somatic chromosome complements numbered 33 in fourteen individuals. In three cases, they were 34, showing that much of the viable pollen of I. C. 1 carried 22.

In five individuals studied, the meiotic divisions were seen to be similar and in one of them more closely so. In the first metaphase, a compact plate is formed and as the chromosomes separate, multivalent associations are seen. There is little lagging in the anaphase. At this stage, the chromosome counts are short of expectation, and on searching, the cytoplasm reveals obliterated chromosomes. At the close of the irregular first division, wedge-shaped cells are seen cut off between the main daughter cells in the dyad.

Although the second division begins with nuclei of varying constitution, it is fairly regularly equational. Polar views of metaphase give counts from 13 to 20, with 16, 15, and 14 as the commonest. The tendency of both divisions, therefore, seems to be towards the elimination of 11 chromosomes, and formation of 11-chromosome pollen grains. The process is not seen to be complete.

DISCUSSION

It is thus evident that the chromosome number in the "normal" F_1 hybrids and the increased pollen fertility presumably resulting from it support the view that the basic haploid chromosome number in bananas is 11. Crossing of *M. malaccensis* with Gros Michel as well as with some other edible bananas results in a combination of the female somatic number with the male haploid number. A case of doubling of the male component together with pollen fertility is also mentioned by White. The explanation of this phenomenon, however, is not clear.

The 44-chromosome hybrids obtained from Gros Michel and *Musa malaccensis* differ physiologically in their resistance to Panama disease, although they look like identical genotypes in other respects. Several ways seem to present themselves in which this 44-chromosome complement is possibly made up, by descent from two parents having 33 and 22 somatic chromosomes, respectively. A similar case of the possibility of chromosome increase after reduction is cited in sugarcanes by Bremer, which supports the present hypothesis that the female chromosome complement passes on undiminished, while only a haploid complement is transferred by the male parent into the hybrid progeny.

About twenty per cent of the hybrid seedlings exhibit a higher chromosome number than the sum of the somatic numbers of their parents, and their explanation is difficult to guess.

The hybrids, like the I. C. 1, show that they receive their main contribution from the female parent, but the constitution of this parent itself is not known. The parent, Gros Michel, however, seems to be a triploid and a descendent of the *Musa malaccensis* group. The added complication of secondary polyploidy is also suggested in the case of bananas. However, the possibility of raising a tetraploid from a commercial triploid, and restoring it back to the triploid condition is demonstrated in these investigations and the practical results obtained are very satisfactory.

2. Hybrids of the Mysore banana [Cheesman, 1932]

An edible type named "Mysore" (Yella Bale) imported into Trinidad from Southern India (and perhaps named after the Indian State, Mysore) was also crossed by pollens from *Musa malaccensis* by Prof. Cheesman "in quest of genetic information". The Mysore is described by him as identical with another type called locally Fillbasket. This variety is said to be immune to the Panama disease, tall and vigorous. Leaves are dark green with reddish flush on midribs and on the lower surface of young leaves. Fruits are small, round, and the bunch is compact. Fruit is about seven inches long, with a pronounced beak, thin skin, and bright golden yellow colour when ripe. Somatic chromosomes number 33.

Twenty-seven inflorescences of Mysore pollinated by *M. malaccensis* yielded 198 seeds in 1929-30, single bunches of fruits yielding as many as fifty-one and thirty seeds each, averaging at seven seeds per bunch. But the seeds germinated poorly. Six of the fifteen seedlings obtained, died in the pot and nursery stages. The study recorded here is therefore of the remaining nine seedlings only with notes on the Mysore × I. C. 1 cross.

In the Mysore meiosis in the pollen mother-cell is the same as in Gros Michel. A compact plate is formed at metaphase which has multivalent associations, not analysed. Some chromosomes lag at anaphase, and stragglers excluded from the daughter nuclei are very prominent in the dyad stage. The second division is semi-regular, with some lagging again. Polar views of metaphase give varying counts both below and above sixteen. Multicellular "tetrads" result, and the mature pollens are very sparse. The number of viable pollens in Mysore variety is very negligible.

F_1 generation

Six of the nine plants mentioned above had 44 chromosomes, and resembled their female parent in vegetative habit, while two had 75 and 73 chromosomes, with thick leaves and dwarf growth. One with 33 chromosomes exhibited wild type habit. The fruits in one plant with normal habit failed to swell without pollination, and developed seeds when they did. Two plants showed parthenocarpy. The thick-leaved plants were similar in habit and chromosome number to the progeny of Gros Michel, and two of these which died prematurely also showed the same habit. The plant with 33 chromosomes was intermediate between the two parents.

In meiosis the usual compact metaphase plate occurs and the semi-regular anaphase exhibits varying number of lagging chromosomes. At the dyad stage isolated chromosomes are seen either cut off by the cell walls or lying free in the main daughter cells. The tetrads are mostly multicellular and the pollen irregular in size, but fairly abundant in quantity.

The cross Mysore ×I. C. 1

With considerable difficulty the Mysore (a triploid) was successfully crossed with I. C. 1 (tetraploid), and a tall and dwarf plants were the progeny, with 54 or 55 and about 90 chromosomes each, respectively. The larger plant which frequently gave counts of 55 chromosomes, appears to be a pentaploid, while the dwarf plant which gave clear counts of 90, suggests the approximation to 88.

Section III

CHROMOSOME NUMBERS IN THE MUSACEÆ

With a view to test the preliminary conclusion that the basic haploid number of chromosomes in the edible bananas is 11, Professor Cheesman, in collaboration with Mr. L. N. H. Larter of the Jamaica Department of Agriculture, carried out chromosome counts in several varieties of bananas. The work was done at Trinidad, the quarantine at Kew, and in Jamaica, and has thrown considerable light incidentally on the proper classification of the genera and species of this sub-order also. The following is a summary of their work in this line.

Of the three sub-groups into which Baker [1893] divided the genus *Musa* L., namely *Physocaulis*, *Rhodochlamys*, and *Eumusa*, the last named group is alone concerned with the origin of the cultivated bananas. Counts of chromosomes detailed here are, therefore, restricted to this group. However, material available on related sections is also examined and included in this study.

All counts were made on root-tips. At Jamaica and Merton, the material was fixed in a modification of La Cour's 2BE, consisting of—

Chromic acid one per cent	90 c.c.
Osmic acid 2 per cent	15 c.c.
Potassium dichromate ten per cent	10 c.c.
Saponin	0·05 grm.
Acetic acid five per cent	20 c.c.
Distilled water	25 c.c.

In subsequent treatment the material was cleared in chloroform, embedded in sixty per cent wax, cut at 20 μ and stained with Newton's Gentain violet.

Chromosome numbers in fertile species of Eumusa

Musa accuminata Colla includes several forms such as *M. simiarum* Kurz., *M. zebrina* Van Houtte, and *M. malaccensis* Ridley. It is common in the Malaya Peninsula and Archipelago, and occurs in a variety of forms connected by all transitions. Crosses between some of the eight distinct clones at the Trinidad collection, were found to be fertile and intermediate in characters. Special attention was given to *M. accuminata*, as it is considered to be the probable parent of some of the dessert bananas.

While recording these counts, considerable difficulty had to be overcome in fixing the nomenclature of the varieties under study, and out of 29 chromosome counts on fertile *Musa* varieties, the somatic diploid number of chromosomes in 27 cases was 22, and in two cases 20. These twenty-seven cases represent at least seventeen distinct varieties, belonging to six different taxonomic species. Two counts, which have 20 chromosomes, were of clones of *M. textilis*. These counts agreed with thos eof D'Angremond for *M. zebrina* and with those of White for *M. accuminata*, but White records the somatic diploid number as 24 for *M. zebrina* and *M. zebrina cerifera* obtained from Malacca. Counts recorded here (which include material from Yella Bale, *M. sapientum*, a Mysore variety) therefore confirm the view that the basic haploid chromosome number is 11 in the *Eumusa* group.

A *Musa textilis* clone differed from other *Eumusa* species in several respects, and would not cross readily with others. A hybrid of *M. textilis* with Yella Bale (*M. sapientum*) from Mysore, however, has been raised, and is under study. It is suspected that some of the distinct varieties found in the Philippines might have originated from the crossing of *M. sapientum* and *M. textilis*.

Some undetermined species are collected at Trinidad Imperial College of Tropical Agriculture, one of which has the habit of edible bananas, but is very fertile with hermaphrodite flowers at the base of the inflorescence. Two of these were obtained from the Royal Botanic Gardens, Calcutta, under the common Burmese name "Taw Byaw".

Chromosome numbers in sterile clones of Eumusa

The great difficulty in studying edible bananas due to their indefinite nomenclature has been fairly overcome by comparing living plants of several varieties, received under different labels and planted side by side. Study of nearly a hundred varieties during the past ten years, in which chromosome counts formed part of the comparison, has enabled the varieties to be reduced to less than thirty, twenty-five of which are considered distinct types. Some of them have sub-types resulting from bud mutations.

In identifying and classifying the many original plants received, the original labels of each are kept intact, and new numbers and standard names are adopted for each on the basis of the groups in which they fall. Each number and standard name denotes a type, and merges several synonyms in it. The name of the country of origin is also maintained in each case, in order to avoid confusion, arising from the same name being used for different varieties in different countries. Difficulty is still noted in the case of a few varieties in determining the true countries of their origin.

From the cytological studies of Professor Cheesman and Mr. Larter, it is clear that in general *Eumusa* species have 22 or 33 chromosomes. In the sterile varieties the chromosomes are 33 except in four varieties studied, where they are 22 only. Edible varieties are, therefore, generally triploid. These studies bring out a fact which materially differs from White's findings, based on 32 and 36 chromosome counts recorded by him. The present view is in agreement with D'Angremond's results, and is supported by a great deal of evidence. Individual discrepancies noticed in counts of chromosomes are attributable to fragmentation, as observed in Ventricosa, Branca, and several clones of Cavendish. In Branca 32 chromosomes *plus* a fragment are seen, which may be chimerical. In Cavendish three conditions of fragmentation are noticed, namely, 33 chromosomes, 32 chromosomes and two fragments, and 33 chromosomes and one fragment (the fragment possibly being a detached portion of one of the normal chromosomes). Fragments are noticed in Canary and other clones also, and fragmentation is perhaps connected with the exceptionally high degree of sterility found in breeding from them.

Occasionally a doubling of chromosomes, as well as binucleate cells and cells with three or more nuclei also, are seen. As previously pointed out, tetraploidy in the hybrids from Gros Michel is not satisfactorily explained by the hypothesis that unreduced eggs might be functioning. The more satisfactory explanation of tetraploidy, based on the present observations, is perhaps that somatic doubling of chromosomes occurs in the zygote after fusion of the haploid gametes. It is also possible in the alternative, that the fusion or loss of chromosomes occurs during mitosis, because different roots of the same Jamaica seedling gave counts of 31, 32, 33, and 34, chromosomes.

Chromosome numbers in other sections of Musa

One species of *Physocaulis* examined, namely, *M. ensete* gave the somatic diploid chromosome number as 18. White [1928] also found the same number in *M. Gilletti*. This observation suggests the possibility that in Physocaulis, the basic haploid number of chromosomes is 9.

Three varieties of sub-genus Rhodochlamys, namely, *M. coccinea*, *M. violascens*, and Musa species undetermined from Sarawak, have given counts of 20 chromosomes each. The two counts of 20 chromosomes in clones of *M. textilis* recorded above under Eumusa, and the differing vegetative habit of one of them may be now interpreted to suggest that these two clones are more closely related to Rhodochlamys than to Eumusa. Similarly, cytological evidence shows that *M. ornata* would rightly fall under Eumusa rather than under Rhodochlamys. Some other species also show greater affinity for *M. ornata* than for *M. violascens*. This suggests that Baker's grouping under Rhodochlamys is not quite natural. These studies show that the probable basic haploid number in Rhodochlamys is 10.

Chromosome numbers in other Musaceæ

Owing to the varying number of basic haploid chromosomes in the different sub-genera of Musa as noted above, counts of other species of *Musaceæ*, namely *Heliconia*, *Strelitzia*, and *Ravenala*, were also made with a view to ascertain the true and common basic haploid number for the whole sub-order, if possible. This end, however, has not been reached.

Six varieties of *Heliconia* were studied. They indicated a diploid condition. One of them had 22 and the rest 24 chromosomes in them, the pairs varying in their lengths. One of the 11 pairs seen in the first variety was very long, perhaps due to the fusion of two normal pairs together, or it may be that fragmentation occurs in the remaining five varieties, which fact accounts for the larger number of chromosomes found in them.

By similarity of chromosomes, *Strelitzia* and *Revenala* appear to be more closely related to one another than to *Haliconia*. The chromosome morphology of these two genera also is similar to that of *M. coccinea* and *M. textilis*. *Ravenala madagascariensis* has a diploid chromosome complement of 22. *Strelitzia Reginae* has a complement of 14 chromosomes, and stands alone with a number lower than 11.

These cytological findings, therefore, confirm the conclusion drawn by Humphrey that *Musaceæ* are a heterogeneous group. The observations recorded here emphasise the heterogeneity not only in the family *Musaceæ* but within the genus Musa itself.

REFERENCES

D'Angremond, A. (1912). "Parthenokarpie und Samenbildung bei Bananen." *Ber. d. deutsch. Bot. Ges.* **30**, 686-91.

——————— (1914). "Parthenokarpie und Samenbildung bei Bananen." *Flora* **107**, 57-110.

——————— (1926). "Voorloopige resultaten van een onderzoek over een kruising tusschen tweezaadproduceeren de Musasoorten." *Handel. Vierde Nederlandsch—Indisch Natuur. Congr. Weltevreden*, 360-67.

Baker, C. A. (1924). "Handboek voor de Flora van Java." (Musa, Afl. 3,130-38) Batavia: Ruygrok & Co.

Baker, J. G. (1893). "A synopsis of the genera and species of *Museae.*" *Ann. Bot.* **7**, 189-222.

Bremer, G. (1928). "De cytologie van het suikerriet. 4. Een Cytologische onderzoek der bastaarden tusschen *S. officinarum* en *S. spontaneum.*" *Meded. Proefst. Java—suikerind.* 565-696.

Cheesman, E. E. (1931, 1). "Banana Breeding at the Imperial College of Tropical Agriculture." *Empire Marketing Board publication, E. M. B.* **47**, London: H. M. S. O.

Cheesman, E. E. (1931, 2). "A note on *Musa ornata.*" *Kew Bull.* pp. 297-9.

——————— (1932, 1). "Gross Mitchel and Pisang Embon". *Trop. Agric.* **9**, 87, 166.

Cheesman, E. E. (1932, 2). "Genetic and cytological studies of Musa, I Certain hybrids of the Gros Michel Banana." *J. Gen.* **26**, 291-312.

———— 1932, 3). "Genetic and cytological studies of Musa, II. Hybrids of the Mysore banana." *Ibid.* **26**, 313-16

———— (1933). "Mutant types of the dwarf banana." *Trop. Agric.* **10**, 4-5.

Cheesman, E. E., Wardlaw, C. W., and Spencer, G. E. L. (1933). "The Cavendish group of banana varieties, with special reference to Lacatan." *Ibid* **10**, 218-21.

Darlington, C. D., and Moffett, A. A. (1930). "Primary and secondary chromosome balance in Pyrus." *J. Gen.* **22**, 129-51.

Dash, J. S. (1925). "Bananas from seed; variety experiments at the Imperial College of Tropical Agriculture." *Proc. Ninth West Indian Agric. Cnf., Jamaica, 1924*, 53-56.

Harland, S. C. (1928). "Bananas and citrus." *Trop. Agric.* **5** (Reprinted from Report of the Colonial Research Committee for 1924 and 1925.)

Howes, F. N. (1928). "The banana in some Tropical Eastern Countries: its forms and variations." *Kew Bull.* pp. 305-32.

Humphrey, J. E. (1896). "The development of the seed in the *Scitamineae.*" *Ann. Bot.* **10**, 1-40.

Jamaica: Annual Reports of the Dept. Agric., 1927-28-29.

Kurz, S. (1866). "Note on the plantains of the Indian Archipelago." *J. Agric. Hort. Soc. Ind.* **14**, 295-301.

La Cour, L. (1931). "Improvements in every-day technique in plant cytology." *J. Roy. Microsc. Soc.* **51**, 119-26.

Larbaud, Mlle. (1920). "Nouvelle technique pour les inclusions et les preparations microscopiques des tissus vegetaux et animaux." *Comptes Rendus Acad. Sci. Paris* **172**, 1317.

Mendiola, N. B. (1926). "A manual of Plant Breeding for tse Tropics." Manila.

Palm, B. (1920). "Preliminary notes on pollen development in Tropical mono-cotyledons." *Svensk Bot. Tidsk.* **14**, 265.

Ridley, H. N. (1924). "Flora of the Malay Peninsula." (*Musa* **4**, 293-95),

Tischler, G. (1910). "Unter-suchungen uber die Entwicklung des Bananen Pollens." *Arch. f. Zellforsch.* **5**, 622-70.

———— (1912). "Uber die Entwicklung der Samenanlagen in parthenokarpen Angiospermen—Fruchten." *Jahrb. f. wiss. Bot.* **52**, 1-84.

———— (1921). "Allgemeine Pflanzenkaryologie." in Linsbauer, K., Handbuch der Pflanzenanatomie. Berlin, Borntraeger.

Wardlaw, C. W. (1932). "Cultivation and diseases of the banana in Brazil." *Trop. Agric.* **10**, 192-7.

Wardlaw, C. W. and McGuire, L. P. (1931). "The behaviour and diseases of the banana in storage and transport." *E.M.B.* **36**, H. M. S. O.

White, P. R. (1928). "Studies on the banana. An investigation of the floral morphology and cytology of certain types of the genus *Musa L.*" *Z. f. Zellforch.* **7**, 673-733.

ABSTRACT

Fibre-maturity of Indian cottons. A. N. Gulati and N. Ahmad (*I. C. C. C. Tech. Bull., Ser. B, No.* **20**).

Among the physical properties of cotton fibre the mean fibre-length and fibre-weight per inch have been regarded important for some time past. Recent work has brought out the importonce of another property namely, fibre-maturity, which is a measure of the thickness of the cell wall of the fibre in relation to its ribbon width. This property is determined by grading fibres under a microscope after they are swollen with 18 per cent caustic soda solution. The influence of environment and heredity on this property and its relationships with other fibre properties and the yarn characteristics of cotton formed the subject of an investigation, which was recently undertaken at the Technological Laboratory and described in the Technological Bulletin, Series B, No. 20.

For the purpose of this investigation thirty-two cottons were selected, out of which thirty were grown in India. The results obtained were analysed with the object of studying (1) the effect of season, locality of growth and heredity on fibre-maturity, (2) the relationships between the fibre-maturity and other principal fibre properties and (3) the influence of fibre-maturity on the neppiness and strength of the yarns spun from these cottons.

It was found that in some cottons fibre-maturity fluctuated from season to season, while in others seasonal fluctuations were quite small. Gadag 1 and Karunganni C.7 are examples of the former while C.A.9 and Mollisoni illustrate the latter. It was further found that samples of Banilla cotton grown in different parts of Khandesh showed significant differences as regards fibre-maturity, while further selections from P.A. 289F grown at the same place (Lyallpur) also showed significant differences. These results indicate the desirability of exercising caution in supposing that selections will follow their parental stock in respect of fibe-maturity or that a cotton which gives good results in respect of fibre-maturity when grown at one place will behave equally well when grown at another place even in the same cotton growing tract.

As regards the relationship between fibre-maturity and other fibre properties, it was observed that on the whole the short-stable cottons possess high fibre-maturity, while the long-staple cottons generally possess a relatively higher percentage of immature fibres. Fibre-weight and fibre-strength were found to be positively correlated with the percentage of mature hairs in a cotton.

The most important effect of the presence of immature hairs in a cotton is the production of neps in the yarns spun from it. The half mature hairs also appeared to be a secondary cause in the formation of neps. The correlation coefficient between the combined percentage of immature and half mature hairs on the one hand and the number of neps per yard of yarn on the other was found to be as high as +0·67 for twenty-ieght samples. These experiments definitely show that cottons possessing a high percentage of immature and half mature hairs should, so far as possible be avoided, as they would yield neppy yarns.

As regards the effect of fibre-maturity on yarn strength, it was found that in long and medium staple cottons, high fibre-maturity went hand in hand with high yarn strength, while in the short staple cottons the reverse was the case. Thus, in the selection of medium and long staple cottons, due regard should be given to fibre-moturity besides the other fibre properties like mean fibre-length and fibre-wight per inch.

Full details of the investigation will be found in the bulletin referred to above (*Authors' abstract*).

NOTE

RESOLUTIONS CARRIED BY THE SIXTH INTERNATIONAL BOTANICAL CONGRESS (AMSTERDAM, SEPTEMBER 2—7, 1935)

1. General Resolution

It is proposed that the Botanical Section of the International Union of Biological Sciences should act as an administrative connecting link between the successive International Potanical Congresses, which maintain their full independence from an international point of view to such an extent that any country which has not joined the Union, will have quite the same rights as those which have joined.

It is proposed that this Botanical Section be authorized to carry through any resolutions, carried by the International Botanical Congresses.

Proposed by A. C. Seward and seconded by J. C. Schonte, C. J. Butler, E. D. Eerrill, N Nemec, M. J. Sirks and N. E. Svedelius.

2. General Resolution

By reason of the growing financial difficulties and the prohibitive price for certain museums and laboratories, of transmission by post, rail and boat, it becomes impossible to guarantee the indispensible exchange of collections of dried plants. It is therefore necessary to obtain for this exchange the free transport now accorded to the exchange of scientific publications.

The Congress asks the Office of the International Union of Biological Sciences to take the necessary steps with various governments in order to obtain this postal privilege.

Proposed by B. G. P. Hochreutiner and seconded by H. Humbert, E. D. Merrill, A. A. Pulle and C. Skottsberg in the name of the meeting of Directors of Botanical Gardens.

3. Section Agr.

That the Seventh International Botanical Congress shall arrange a Section for Agronomy on the same lines as that of the Sixth Congress.

Proposed by the Section for Agronomy.

4. Sections Cyt. and Gen.

That the Botanical Section of the International Union of Biological Sciences on behalf of the Sixth International Botanical Congress may apply to the International Committee for Genetical Congresses for the appointment of an International Committee to study the different meanings of various cytological and genetical terms used in the literature, to propose exact definitions of these terms and to suggest if and what further steps are necessary to improve the terminology of genetics and cytology.

Proposed by F. W. SANSOME and seconded by M. J. SIRKS.

5. Sections Cyt. and Gen.

The Sections of Genetics and Cytology of the Sixth International Botanical Congress take the occasion of their presence in Holland to record the deep sense of debt which the sciences of Genetics and Cytology owe to Hugo de Vries. It is a satisfaction that he could live to such a ripe old age and thus see imposing structure which has been erected on the foundations in the laying of which his painstaking investigations and prophetic vision had so large a share.

The Honorary Secretary of the Congress is hereby requested to spread this resolution on the minutes of the Proceedings and to send a copy to Mrs. de Vries with the sympathy of the Congress and with the assurance that Hugo de Vries will remain for all time an inspiration to biologists and live as one of the immortal heroes of Science.

Proposed by A. F. BLAKESLEE and seconded by F. OEHLKERS and E. W. SINNOTT.

6. Section Geo.

The Sixth International Botanical Congress at Amsterdam, 1935 appeals to all botanists and cartographists with the request that they should employ for the same plant communities the same colouring and for sociologically related plant communities, especially in survey maps, similar tints, in accordance with the proposals which the Fifth International Botanical Congress put forward at Cambridge. Should the case arise necessary modifications shall be accounted for.

7. Section Geo.

The Sixth International Botanical Congress draws the special attention of Public Bodies, Scientific Institutes and Societies for the International Protection of Nature to the regrettable danger of inconsiderate destruction of primitive vegetation to which, in the future vast territories especially in tropical and sub-tropical countries, will be exposed through the nefarious practice of brushwood and prairie fires.

It points out the often radical changes brought about by this practice in the biologic complex constituted by the community of plants and animals. On the one hand, a very great number of species are threatened in a short time with total extinction; many of them being of the greatest interest from the scientific, aesthetic and economic points of view. On the other hand, countries formerly covered with a woody vegetation of various types, are becoming, or are in process of becoming, deserts in consequence of the changes which the destruction of this vegetation produces upon the local climate, the hydrologic conditions and the physico-chemical characters of the soil.

The Congress emprasizes the necessity:

(1) Of constituting in these countries permanent and fairly extensive reserves for safeguarding the equilibrium of the natural conditions and the living members of the vegetable and animal kingdoms (National Parks);

(2) Beside the territories thus constituted as permanent Reserves, to lessen in some measure the consequences of the deforestation and exploitation by maintaining an adequate proportion of forest areas, taking this in its widest sense;

(3) To prevent the substitution of natural formations of woody autochtones by those of exotic species (in accordance with the conclusions of the International Conference for the Protection of the Fauna and Flora of Africa, London 1933).

Proposed by H. HUMBERT, P. G. van TIENHOVEN and seconded by R. BOUILLENNE, J. BURTT DAVY, A. CHEVALIER, L. EMBERGER, A. W. HILL, J. JESWIET, P. LEDOUX, R. MAIRE, E. D. MERRILL, G. NEGRI, I. B. POLE EVANS, J. RAMSBOTTOM and A. WILCZEK.

8. Section Geo.

The Sixth International Botanical Congress is conscious of the great dangers. that result from the destructions of tropical and subtropical vegetations, and also of the perturbations caused in such regions by the action of man.

The Congress insists upon the study of these problems by the botanists of these countries and that they may inform their governments.

The Congress demands especially that these informations shall be collected and that they shall be published in view of a most efficient protection of the indigenous vegetation.

The Congress appoints a Committee for studying this subject and for submitting a report to the Seventh Congress. The following members of this Committee are nominated: I. B. POLE EVANS, president; H. HUMBERT E. D. MERRILL and J. NABELEK, vice-presidents; R. BOUILLENNE, H. BROCKMANN

Jerosch, A. Chevalier, L. Emberger, A. W. Hill, J. Jeswiet, P. Ledoux, R. Maire, G. Negri, L. R. Parodi and M. F. Gallego Quero and as Secretary J. Trochain.

Proposed by I. B. Pole Evans and seconded by H. Humbert.

9. Section Geo.

That the programme of the Seventh International Botanical Congress shall contain the study and the delineation of the characters of the various types of steppes, their origin, their development and especially the discriminative criteria for climatic associations and secondary associations which get confused under the names "steppe", "prairie", "Savannah" and the definitions of the corresponding phytogeographic regions.

Proposed by H. Humbert and seconded by L. Emberger, H. Gams, R. Maire, R. Bouillenne, A. Eig, G. Negri, J. Trochain, H. Bojko, P. Ledoux, A. Conard, E. Wilczek, E. Scheid and J. Podpera.

10. Section Geo.

A committee shall be appointed to elaborate proposals for a classification of climates from a phytogeographical point of view and to submit them to the Seventh International Botanical Congress.

Proposed by L. Emberger, and seconded by H. Brockmann Jerosch, S. P. Agharkar, A. Chevalier, A. Eig. H. Gams, H. Humbert, P. Ledour, T. Lippmaa, R. Maire, G. Negri, R. Pampanini, I. B. Pole Evans, J. Trochain.

11. Section Geo.

The Geobotanical Section of the Sixth International Botanical Congress recommends:

(1) to use the term *Sociation* for vegetation units characterized mainly by dominance in the different layers, in the sense of Scandinavian plant sociologists;

(2) to use the term *Association* for vegetation units characterized mainly by characteristic and differential species in the sense of Zürich Montpellier plant sociologists, or at least for units of the same order of sociological value; *Subassociation* and *Facies* can, where necessary, be used for their subordinate units;

(3) to unite sociations and associations into alliances in the sense of Zürich-Montpellier plant sociologists, and the alliances into higher units.

Proposed by J. Braun Blanquet, G. E. Du Rietz and R. Nordhagen.

12. *Sections Myc. and Path.*

The Sixth International Botanical Congress wishes to express its sincere appreciation of the admirable work accomplished by the Centraalbureau voor Schimmelcultures at Baarn since its foundation in 1906 and views with grave concern the present financial difficulties of what is essentially an international institution.

Proposed to the Section Myc. by J. Ramsbottom and seconded by E. J. Butler; to the Section Path. proposed by E. E. Rhiem and seconded by E. C. Stakkan.

13. *Section Path.*

The Committee on Description and Nomenclature of Plant Viruses appointed by the Fifth International Botanical Congress, 1930, wishes to report that it has made progress in developing a scheme for the nomenclature of plant viruses and suggests to this congress that the Committee be empowered to continue its considerations and establish an acceptable system of virus nomenclature.

Proposed by H. M. Qaunjer and seconded by James Johnson, P. A. Murphy, J. Henderson Smith and G. Samuel.

14. *Section Path.*

It is recommended that the term "physiologic race" be substituted for "physiologic form" as the former seems more appropriate. It is recommended further that the word "race" be used in general to designate biotypes or groups of biotypes that differ from each other in physiologic characters.

Proposed by E. C. Stakman and seconded by Miss M. Newton, Miss G. Millbrink and Th. Roemer.

15. *Section Path.*

The Sixth International Botanical Congress expresses itself of the opinion:

that an effective and unceasing campaign against destructive plant diseases and insect pests can be successfully persecuted only by international action and mutual co-operation;

that close and frequent international discussion of the problems of plant quarantines should take place to bring about improvement of the health conditions of plants and plant products offered for export;

that it unanimously recognizes that such section will greatly facilitate international trade in the commodities concerned; and

that, finally, this resolution be brought to the attention of the League of Nations, emphatically endorsing the League's proposal to give this matter the urgent and careful consideration with a view to facilitating and expediting the purpose and aims of this resolution.

Proposed by H. T. Gussow and seconded by N. van Poeteren.

16. Section Sys.

The Sixth International Botanical Congress agrees to the following propositions by the International Standing Committee for Urgent Taxonomic Needs:

(1) Compilation of a new Phytography. The book should not treat the whole content of De Candole's "Phytographie"; it should prepare a new compilation of the collections represented in the larger herbaria of the world. The institutes are asked to draw up a list of their collections.

(2) Photographs of Type Specimens. The Scheme to photograph the types of all plants is important, and should be encouraged, but involves very great expenses. As the means of most Institutes are restricted at the present time, this point should be postpond to the next Congress.

(3) International Dictionary of Botanical Terminology. The Dictionary should be restricted to Phanerogams. The Cryptogams are to be worked out by specialists of the individual groups. The Latin word should be translated and explained in English, French and German. For use in countries of other languages the botanists of such countries should supply translations. All terms would be given in alphabetical sequence. At the end, the most important terms for single categories (f. i. leaf, root, Orchids) might be placed together once more.

(4) It is highly desirable, that the specimens of the Linnean type specimens at the Linnean Society and at the British Museum should be photographed.

Proposed for the International Standing Committee for Urgent Taxonomic Needs by L. Diels and seconded by A. D. Cotton, R. Fries, R. Maire, E. D. Merrill and J. Ramsbottom.

17. Section Sys. Subsection Nom nclature

Votes of Thanks.—To the Editorial Committee of the International Rules of Botanical Nomenclature, ed. III (1935), namely Professor Harms (General Editor), Dr. Rendle and Professor Hochreutiner, for the successful manner in which they carried out their difficult task.

To the Executive Committee of the Fifth International Botanical Congress, Cambridge, 1930, for defraying the cost of publication of the "Synopsis of Proposals" and "Preliminary opinions" concerning nomenclature.

Resolution.—That the Sixth International Botanical Congress accepts the decisions of the Section of Taxonomy and Nomenclature concerning the modification of the International Rules of Botanical Nomenclature, ed. III (1935) and sanctions the appointment of the Standing Committees by this Section.

Proposed by E. D. Merrill and seconded by L. Diels.

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